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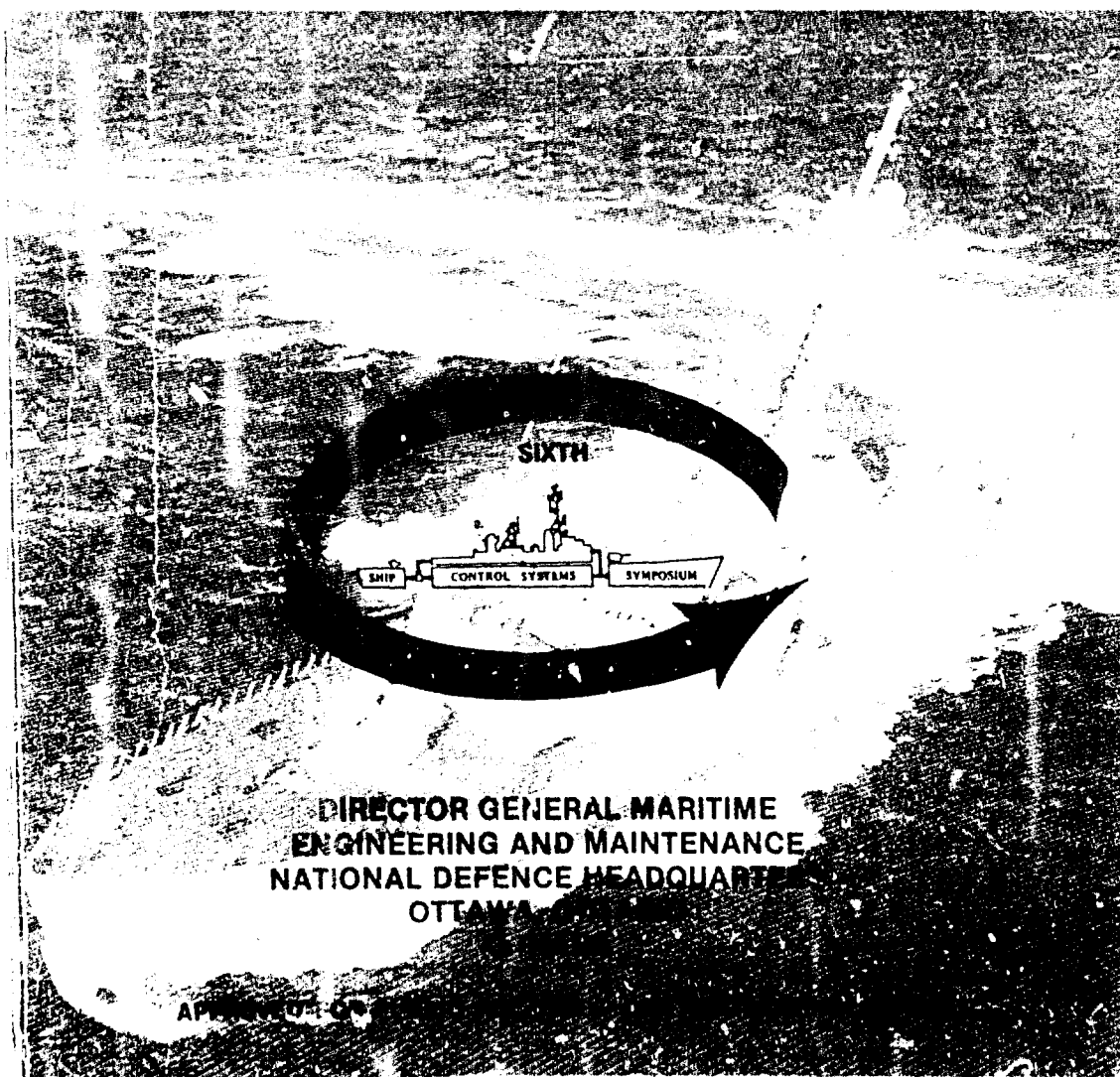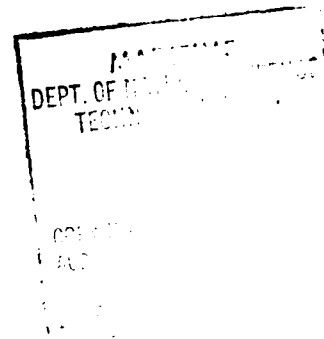
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FOREWORD

The Director General Maritime Engineering and Maintenance (DGMEM) is pleased to present the Proceedings of the Sixth Ship Control System Symposium held at the Chateau Laurier/National Conference Centre complex in Ottawa, Canada, 26-30 October 1981. This is the sixth in a series of symposia on ship control systems. The First Ship Control Systems Symposium was convened in 1966.

The technical papers presented at the Symposium and published in these proceedings cover the entire spectrum of ship control systems and provide an insight into technological developments which are continuously offering the ship control system designer new options in addressing the complex man/machine operation. The microprocessor and its apparently unlimited development potential in future digital, distributed control systems appears ready to reshape the conventional concepts now so familiar in control system designs. There are many concerns that the advantages of the new technologies will be negated by the inability of training systems to graduate technicians who can adequately cope with these new systems.

The response to "Call For Papers" was outstanding and the papers selection committee constrained by the time available for presentations, was hard pressed to make their final selections from the many fine abstracts submitted. The final papers represent a unique international flavour which includes authors from every facet of the ship control system community. The final program is a balance of both theoretical and practical control system papers.

These Proceedings constitute the major record of the Sixth Ship Control Systems Symposium. The contents indicate the success of the Symposium and provide some insight into the effort that was required to ensure this success. The Symposium organizing committee, advisory groups, publications branch, authors, session chairmen, international coordinators, clerical and administrative personnel, and management all provided positive and cooperative support to the many tasks that had to be performed in organizing and presenting the Symposium.

This Symposium has continued to explore and present a number of specific aspects of ship control systems and undoubtly the next symposium will include new concepts and ideas which were unavailable for this Symposium. As in the past, we hope these Proceedings become a source document on ship control along with the previous proceedings. It is our hope that the Symposium has provided stimulation to those who will continue to advance this technical field.

Bruce H. Baxter
General Chairman

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Philip V. Penny
Technical Chairman

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WARSHIP PROPULSION CONTROL SYSTEMS -

A CANADIAN FORCES PERSPECTIVE

Captain(N) D.J.S. Reilley, CF

Cdr B.H. Baxter, CF

SUMMARY

1.   The aim of this paper is to present the dilemma now facing warship propulsion control systems designers as they attempt to achieve exacting system performance requirements in an unstable technical and personnel environment. The Canadian Forces (CF) experiences with the DDH 280 propulsion control system will be used to illustrate how the failure to appreciate the impact of technically advanced systems on personnel in general and the military training organization in particular can result in problems which negate the advantages offered by technical innovation. The influence of adverse demographic projections on the designer's decision will be discussed and developed as a critical factor in the man-machine equation. The CF Ship Integrated Machinery Control System (SHINMACS) concept will be offerred as an option to the propulsion control system designers attempting to achieve specified operational requirements within the realities of a personnel conscious military organization.

INTRODUCTION

2.   Previous ship control system symposia have served to focus a new awareness of adopting a total integrated design concept when specifying systems for complex warship designs. Frequently the designer in his eagerness to provide increased capability through technological advances fails to adequately assess the impact the new technology may have on related personnel trainings systems. Today the propulsion control system designer, faced with an accelerating increase in micro-electronic components, must temper his design decisions with an analysis of previous designs and their in-service performance.

3.   Automation within a manpower limited organization continues to receive considerable discussion and it is generally conceded that, in those warship designs where automation was specified as integral to manning reductions, in-service design limitations resulted in unplanned maintenance requirements which could only be met by the introduction of material and personnel resources which were designated to other high priority projects. The additional resources may resolve the technical problem but the overall effect on the designer's credibility may result in future 'design guidance' which effectively eliminates new technical advances in favour of conservative, time proven concepts. This loss of initiative can result in systems and equipments that lack the flexibility to cater for changing personnel and technical conditions. A review of the CF DDH 280 propulsion control system illustrates how non-technical considerations were able to produce long term operational problems which have brought unnecessary criticism to a significant technical achievement.

DDH 280 EXPERIENCE

4.   There is a tendancy to critically review the decisions of previous propulsion control system designers with a retrospective insight which was unavailable to the original design team. The complex cause and effect relationships which were at best conceptual design assumptions tend to crystalize with the passing years and criticism is directed at system designers whose only fault was in specifying a system within the bounds of existing personnel and budget realities.

5.   The DDH 280 is a 50,000 SHP COGOG (combined gas or gas) destroyer incorporating state-of-the-art 1965 technology. Although other navies and some merchant vessels had experimented with gas turbine propelled vessels, the DDH 280 was the first operational warship to successfully commission the COGOG machinery arrangement. The propulsion control system includes:

Propulsion Control - COGOG 50,000 SHP

. 2 FT 4 (25,000 SHP), 2 FT 12 (3400 SHP)

. Controllable Pitch Propellers

. Pneumatic, Hydraulic Control

Bailey 760 Sequencer - Analogue, Hard Wired

. Engine Start, Stop, Trips

. Engine Selection

. Control Station Transfer

Bailey 750 Data Logger - Digitized Analogue Inputs

. Periodic Data Logger

. Demand Logger

. Alarm Logger

6.   These systems remain the design basis for warships enterring service today and although the DDH 280 has experienced some system failures, the overall assessment of these control systems is favourable. The selection of a pneumatic control system is often questioned and the simple answer is that in 1965 electronic control systems were unproven, unreliable and unavailable. Granted, the pneumatic control system is now technically obsolete and the maintenance resources necessary to support the system are excessive; but these problems are resolvable within the normal technical updating process which normally characterizes all warships. Current CF DDH 280 update programmes include plans to modernize the entire propulsion control system with available 1981 technology.

7.   The DDH 280 represented a quantum step forward in marine systems technology which was under-estimated in terms of training and support requirements necessary to achieve the transition from steam to gas turbine technology. The gas turbine with its inherent high rotational speeds required a responsive control system which was beyond manual capability. Initial crews were hand picked and given special technical training to prepare them for the new ships. A small group of tradesmen exhibiting special control system aptitudes were trained as control system technicians but the majority of DDH 280 marine engineering personnel received only limited controls training. Initial operating experiences pointed out that necessary documentation in the form of technical manuals, drawings and maintenance procedures was inadequate and that fault finding and rectification within the complex propulsion control system was manpower intensive and in some instances merely a hit and miss exercise. The cost in preparing the necessary DDH 280 technical documentation today is staggering and again diverts scarce resources. The CF in 1965 was primarily a Y-100 steam turbine navy and it was almost 10 years before the technical training schools were able to introduce gas turbine technology into existing training courses. In spite of these shortcomings the DDH 280 has proven itself a reliable propulsion system and the hard lessons

'earned will be applied to all future warship designs to ensure the design process integrates the technical and personnel requirements into a total system concept.

DEMOGRAPHIC INFLUENCES

8.   Any decision to specify technically advanced concepts for warships in an all volunteer military system must be balanced by a realistic assessment of demographic trends. Failure to appreciate the impact of adverse demographic trends can spell ruination for those system designs which are unsupportable in terms of human resources. Figure 1 illustrates the Canadian population in terms of potential 17-24 year recruits for the period 1968-1990. Although the curve shows we are now at the peak of the 'baby boom', recruiting is less than ideal and in the next 10 years the situation may become critical. Existing recruiting criteria with respect to sex, age and education will have to be waived if sufficient recruits are to be found.

**MALE AND FEMALE POPULATION AGED 17-24
IN THOUSANDS FOR TWO YEAR PERIODS 1968-1990**
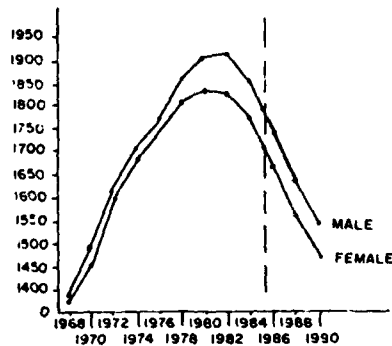
FIGURE I

9.   The recruiting problem is further complicated by educational trends (FIGURE 2) which clearly shows a significant increase in that segment of the Canadian school leavers who elect post secondary education. These students do not traditionally join the military, so recruiting quotas are filled from the lower, less educated group, who have chosen to opt out of what is generally conceded as an 'easy' school system. Their potential as eventual high technology technicians is questionable.

A1-3

MALE AND FEMALE SCHOOL LEAVERS IN THOUSANDS
ACTUAL AND PROJECTED FOR SELECTED YEARS BY
GRADES 8,9,10 AND 11,12 IN CANADA

KEY:
GRADES 8,9,10 — — —
GRADES 11,12 ———

LATERAL ENTRY RECRUITS

CF RECRUITING DOOR

FIGURE 2

10. These trends present the system designer with a double edged dilemma. On one side he sees new technical innovations whose implementation requires recruits of higher skill levels than are now in the personnel inventory while on the other side he sees a shrinking manpower pool characterized by less capable recruits. If he abandons the new technologies for simpler systems which can be mastered by the available recruits, he soon realizes that the numerical realities

of Figure 1 will not provide the numbers of tradesmen necessary to operate and maintain the systems. One solution is to develop a recruiting and training concept which will attract sufficient high calibre recruits from the upper Figure 2 curve. The CF have initiated a new recruiting concept designated lateral entry which recruits high school graduates by offerring them subsidized education and accelerated rank upon graduation. The pilot project is now in its second year and initial evaluations are v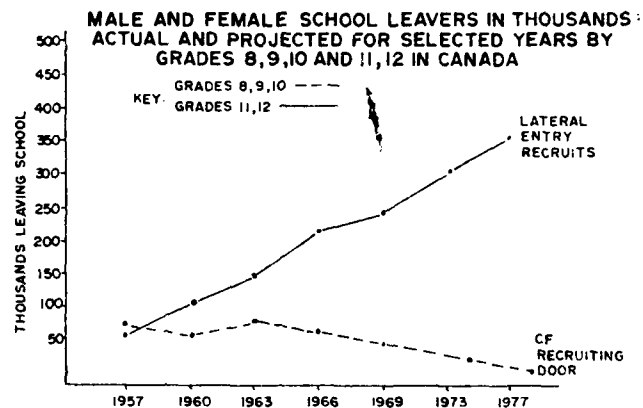ery encouraging. The lateral entry recruit studies a programme based on the latest high technologies which are planned for future CF systems. It is expected that the lateral entry concept will expand rapidly in the next few years to include all CF technical trades.

TECHNOLOGY IN THE 1980's

11. It is estimated that today's ship control system designer has available to him only 10 percent of the 1990 technology. The advances in micro-electronics are occurring so rapidly that it is virtually impossible to develop a conceptual design which will remain technically relevant over the normal 7 to 8 year warship acquisition period. The designer can at best structure his design so that interfacing systems and equipments maintain a flexible modular characteristic so that innovative developments can be adapted without total system replacement. The developing concepts of standard digital equipment (SDE) and distributive system architecture appear very promising and all ship designers and planners are actively funding development programmes that will demonstrate the capabilities of these new system concepts. The CF's SHINPADS and SHINMACS concepts are but two examples of this new digital distributive concept which will be presented during the symposium.

A1-4

12.   There is a decision point in every warship acquisition programme when the
system designers must make their choice of candidate systems and equipments which
will achieve the stated performance requirements within an acceptable technical
risk. Those promising technical developments with excessive risk cannot be
included in the design as their potential failure can result in unacceptable cost
and personnel requirements.

13.   The key to the future systems is undoubtedly the silicon chip with its
unbelievable capacity to store hundreds of thousands of information bits on a
postage stamp size block. The low cost, reliability, redundancy and computing
power of these chips make them inevitable components in all systems and hardwares.
Some chip manufacturers are now placing entire systems on a single chip and
giving the control system designer the capability to specify individual component
control systems which were previously limited to the overall or central system
control. The entire control of a gas turbine including fuel scheduling is now
possible on a single chip.

14.   Electronic and digital components have demonstrated high reliability
performance and designers are no longer reluctant to specify them for ship control
systems. In most applications the repair by replacement on exchange nature of
the electronic and digital components lends itself well to the condition based
maintenance philisophies which appear to be evolving in most naval maintenance
management systems.

15.   The unprecedented capabilities of the new micro-electronics and their
associated mini-computers and micro-processors are not without serious concerns
in the areas of software costs which appear to be rising at an alarming rate.
Programmers for real-time sophisticated military systems are difficult to find and
the management of software has become a serious concern. Most system design
authorities are developing rigid software criteria which should provide the
necessary control through standard digital equipment and software languages. The
eventual development of a standard compiler such as ADA will do much to resolve
the existing software problem.

CANADIAN FORCES PROPULSION CONTROL PHILOSOPHY

16.   The critical influence in all warship propulsion control design decisions
over the next 20 years will be the shrinking manpower pool. Any decision which
fails to address this reality will be subject to severe criticism and, if not
challenged could result in future manning problems which could seriously impact on
operational, capability. Those existing CF warships which are planned to undergo
mid-life or major conversion programmes must also be assessed against projected
manning reductions and, wherever feasible, new, less manpower intensive systems,
must be proposed. In determining the level of technology which can be supported
within the existing CF trade structure it will be necessary to review traditional
recruiting concepts to see where new sources of high calibre recruits can be found.
Programmes such as the current CF pilot project to assess the feasibility of
lateral entry must be exploited and expanded as quickly as possible. The CF will
continue to observe Canadian industry to see how they address similar technical
problems and, if compatible, the CF will adopt the proven ideas and concepts of
industry. The growth of controls and instrumentation technicians in the civilian
sector has prompted the CF to review its existing requirements for these
technicians and it is conceivable that specialized controls and instrumentation
tradesmen will become a separate CF marine engineering trade in the future.

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17.   The CF will continue to work with Canadian industry in developing equipments and system concepts which turn technical innovations into available propulsion control systems. System design criteria will be carefully stated to ensure whatever systems that are developed address the Canadian requirements.

18.   Digital, distributive systems incorporating graphics and ergonomically designed displays and consoles appear most capable of meeting present and future Canadian needs. The reliability and flexibility of electronic and digital components should offer a range of system performance which is unavailable in existing ships today. The silicon chip now provides a computing and memory capability which can be programmed to assist every system operator in performing his watchkeeping duties. No longer will watchkeepers be required to memorize countless operating and emergency procedures. All system information will be stored and available for instant recall. The ability to employ the digital architecture as a training simulator will prove an enormous benefit if rising fuel costs begin to limit sea training periods. SHINMACS and other digital systems which offer these new concepts in control system design are still only research and development projects which will require at least 2 more years before the concepts are demonstrated.

CONCLUSION

19.   The challenges of the 80's demand a new awareness from propulsion control system designers who are tasked with providing operationally capable warships in an uncertain technical and personnel environment. No longer will the design engineer, the research and development scientist and the personnel planners be able to work in isolation, for failure of   one to totally appreciate the limitations of the others may result in new systems which are unsupportable. The design engineers must step back from his ever changing technical world and assess his ideas and concepts not only against past designs but also against the projected realities of the future. Technology must not be allowed to grow unchallenged, but be expanded under the positive control of designer engineers whose ultimate aim must be to direct technical innovations towards total integrated systems that will achieve specified performance under the most stringent conditions. The task will not be easy but the cost of failure will be absolute.

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OBJECTIVES AND IMPLEMENTATION OF FUTURE
WARSHIP CONTROL AND SURVEILLANCE SYSTEMS

by Cdr. E. D. M. Floyd, R. N. ,MOD(PE), Bath. UK
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INTRODUCTION

At the Fifth Ship Control System Symposium at Annapolis, the UK MOD
presented a series of inter-related papers (References 1 - 7) that covered the
activities that had been undertaken during their research programme, and
outlined the major development activities that they were planning to initiate. It
is appropriate, therefore, that three years later in this paper and its associated
papers (References 8 - 11), an attempt should be made to present the progress
of these development projects, the problems that have been encountered, and
the extent to which the original design objectives have been met. This paper
will cover the broader aspects of where the MOD currently stands, and will act
as an overview to the other papers presented by the MOD, their consultants and
industry, which will discuss some of the main areas in greater detail.

In developments of this nature where the maximum safe use of advanced
technology is being sought, it is almost inevitable that the path leading from
the early system concepts to the production of a system for installation in a
ship should not be a smooth one. However careful and conscientious one may
be in trying to learn from the mistakes of the past, and however forward
thinking one may be in trying to identify the new problem areas, large and
complex programmes of the sort that will be described have indeed thrown up
unexpected difficulties, and shown up certain shortcomings in the approach that
has been taken. These are all covered in the companion papers, along with the
steps that have been taken, or have been proposed, to overcome them.

Now although it must be stressed that in the UK the developments under
discussion are by no means finished nor the designs evaluated, nevertheless
it is an excellent discipline to recall the original design objectives and examine
critically the advantages that were foreseen, to see how far they are being
realised in practice. Finally the lessons that have been learnt by the MOD, its
consultants and its contractors will be highlighted.

BACKGROUND

The analogue propulsion control and surveillance systems that have been
fitted, and are still being fitted in the Royal Navy gas turbine ships, are
working well and giving very little trouble. Failure rates are low, fault
finding facilities are good, and comprehensive shore training facilities are
provided for operators and maintainers, and these factors, when allied to the
GT propulsion plant designs themselves, have resulted in a situation where
there is no record of any operator errors leading to major machinery damage.
This is a far cry from the record of comparable steam plants and their

A 2-1

associated controls. The current analogue control and surveillance systems are, however, of dated design, and, inevitably, problems of obsolescence cannot be that far off. It was the realisation that a new generation of control and surveillance systems would be required for machinery to be fitted in the next surface ship project that led to the MOD setting up a Technical Co-ordination Group to propose a detailed programme of research and development work in the Machinery Control and Surveillance (MC & S) field. This led in 1975 to the setting up of the MC & S Research Programme, the full scope of which was described in a paper presented at the Fifth Ship Control Systems Symposium (Reference 1). The programme ranged from the consideration of broad ship level concepts through the spectrum to detailed hardware design. Because there was, at the time, no specific ship programme at which the work was directed, it was essential to ensure that the results were applicable to the widest possible range of ship types. The objectives set for these studies were:

(a) To establish the broad requirements for automation in future ship systems and establish a rational basis for arriving at the optimum balance between man and automation.

(b) To prepare for the introduction of new technology in the most cost effective applications.

It is not necessary here to detail all the outputs from the twenty or more studies that were undertaken by industry, universities, MOD consultants and other Directorates within the MOD, but note will be taken of certain key decisions that emerged which were central to the whole strategy that evolved.

Although the first development project to be undertaken was for surface ship propulsion systems, in fact the research activities had been undertaken to look at the full spectrum of ship machinery. Current RN ships are fitted with a wide range of analogue electronic, fluidic, pneumatic and mechanical control systems, and it was realised that major cost savings would stem from the adoption of common policies and, wherever possible, common technology. A committee was set up within the MOD with the task of ensuring that, in advance of an actual ship design, all developments in this field would lead to equipments that would be compatible, one with another, in a ship environment. Every effort was to be made to ensure that a high degree of commonality was achieved in areas such as the level of automation to be fitted, the design standards to be applied, the concepts of machinery operation and the approach to vulnerability.

From the programme of research arose the concept that future propulsion control systems will be based on digital technology using microprocessors and multiplexing in a distributed configuration, as opposed to the centralised concept used in the current generation of analogue systems. The decision was taken to initiate a major development programme around this concept and design such a control and surveillance system for a notional ship with a propulsion package of 4 SM1A Spey Gas Turbines in a COGAG arrangement driving into a controlled pitch propeller (CPP system). This came to be known as the Reference Ship. In practice it has been found that the normal lead

A 2-2

time between the tabling of a Naval Staff Target for a new Class of ships and the time when production equipment is required at the dockside, is inadequate for the proper and orderly development, evaluation and production of a new control system, and thus the aim was set to produce a system that was as near ship independent as possible. The role of simulation studies in the design and development of control systems is discussed in an associated paper (Reference 8).

CURRENT DEVELOPMENT PROGRAMME

The current development programme consists of a number of areas of activity, some of which are in a major development phase, while other activities are progressing at a slower pace. Those where the greater effort is being applied presently are the Propulsion Control System Demonstrator, the Propulsion and Auxiliary Secondary Surveillance System (PASS), and the Evaluation Centre. The activities currently being pursued in a lower key are Continuation Trainers, Auxiliary Control Systems, and the design of Ship Control Centres (SCC).

Propulsion Control System Demonstrator

As discussed earlier, there was a need to gain experience in digital technology systems and therefore it was decided to design and manufacture a "Demonstrator" system which could be evaluated at the Evaluation Centre from an operational and user viewpoint, while allowing valuable experience to be gained in the implementation of this new technology. The Demonstrator system encompassed the Propulsion Control and primary surveillance based on the machinery configuration of the Reference Ship as described above. The concept was derived from the test rig system reported at the Fifth Ship Control Systems Symposium (Reference 5) and comprised a distributed computer system as shown schematically in Figure A. Briefly each major item of plant and every control position would have distributed intelligence in the form of a micro-computer together with the unit which undertook the System Control functions called the System Control Unit (SCU). The communications between these computers would be by means of high speed serial communication lines. It was planned that the quality of the hardware build would be pre-production standard and the software to full long life-time production standards. At the time of writing this paper the system hardware has been completed and system communications are being set to work, with the system integration and setting to work at the Evaluation Centre phases still to follow. On completion a decision will be made as to whether the system will be fitted in the next class of ship, and on what further work must be undertaken to match this system to the propulsion package selected for that ship.

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The PASS System

The second major development programme that was set up was for a system known as the Propulsion and Auxiliary Secondary Surveillance System, (PASS). The research programme identified the need to separate surveillance into 2 types:

(a) That needed by the operators at their control panels for normal operation of the systems and to carry out breakdown drills, and for the safe reconfiguration of the systems thereafter.

(b) Additional information available to both the operator and the maintainer that need not, and indeed should not, be permanently displayed at the main panels. This requirement is the one that is met by PASS and is the subject of a later paper (Reference 9).

The system is essentially a machinery surveillance system again using distributed computer based techniques designed to gather a large number of plant parameters (typically 1000) and process and display the information using Visual Display Units such that this information is in a readily assimilated format. The system displays dynamic information in a hierarchical structure of "pages" presenting information on system schematics, history of parameters, maintainer assist pages including trend graphs and performance calculations and provides a comprehensive logging facility.

The development programme for the PASS system comprises a number of stages. The objective of Stage 1 is the development of a prototype system to enable the operational and user requirements to be fully evaluated, and to prove the system design concept.

The approach taken to accomplish this objective was to develop the software on commercial hardware, the computer type being selected principally on hardware availability and the quality of software development tools. As in the Demonstrator Project, the software is being developed to be transportable across computer types, and it is therefore anticipated that the large majority of the software will eventually be used on the final ship system. This approach enables the final selection of hardware for the ship system to be delayed for as long as possible to take advantage of the latest advances in technology whilst also proving the system concept functionally with low development risk.

If the system is approved for the new Class of ship then Stage 2 of the development programme would commence and involve the matching of the system to the ship requirements. Stage 3 would develop a pre-production system using the computer hardware destined for the ship.

Evaluation Centre

Experience with the earlier generation of analogue electronic systems when first fitted in the Type 21s and Type 42s had not been satisfactory and had led to many design investigations and subsequent modifications. Recognising that the problem arose largely from the lack of a facility in which to evaluate the control system adequately before fitting it in a warship, it was decided that in future all new control and surveillance systems would be fully evaluated in a purpose built Evaluation Centre.

This facility would contain real time computer simulations of the machinery, together with the necessary electronics to interface to the control and surveillance system hardware. It would thus be possible to assess any new control concepts being introduced and to carry out a comprehensive evaluation of the new systems before placing a production order for First of Class hardware. Quite apart from proving that the system would perform its actual control functions satisfactorily it would be possible to investigate aspects such as failure modes, maintainability and operability. At a later stage it would be used for the investigation of in-service problems and proposed modifications. This facility is now operational and is discussed in a companion paper (Reference 11).

Auxiliary Control Systems

The current status with regard to auxiliary control systems is that the definitions of the control tasks have all been formalised. However, it has been found that the implementation phase is very dependent upon the actual ship plant, and therefore until a ship has been specified not much more can be done. It is envisaged that further work would be carried out during the early stages of an actual ship programme. There is undoubtedly a very close link functionally and technologically between auxiliary control and the more developed systems of Propulsion Control System and PASS, and therefore the degree to which auxiliary control can be accommodated by or within these systems is being investigated.

SCC Design

The design of Ship Control Centres can be described as a judicious blend of the experiences and lessons learned in operating ships from centralised control positions, and integration of the Propulsion Control, PASS and NBCD system as a co-ordinated control centre. Furthermore due cognizance must be taken of the necessity to produce a Ship Control Centre which is inherently safe to the operator while at the same time providing an interface to the computer which is in a convenient form for digital systems, and taking advantage of the advances in ergonomics and technology related to displays etc.

There is currently no document which helps in the design of SCCs and so it is the intention to produce a Design Guide which it is hoped will fill this gap. It is also envisaged that much more use will be made of low cost mock-ups linked to computer simulations of the proposed plant to enable operator reaction and the SCC design to be assessed.

A 2-5

Continuation Trainers

Studies are being undertaken to identify the most effective method of
carrying out follow-up or continuation training for machinery watchkeepers once
they have left their shore training establishments and gone to sea. From a cost
effective viewpoint there is a strong case to be made for using existing
equipment on-board ship for this task. A method of achieving this would be for
the ship to go into local control of the propulsion machinery when cruising, so
enabling the propulsion part of the SCC console to be used in conjunction with a
simulation computer for training. Currently this work is at the feasibility stage.

DESIGN OBJECTIVES - HAVE THEY BEEN MET?

The Propulsion Control System Demonstrator is the only system discussed
in this paper which has progressed sufficiently at the time of writing to address
this question to; but we will see later that, as a result of lessons learned, the
approach taken on the PASS system is significantly different in parts.

Firstly, looking at sofware, the design objective here was to produce
software to a high standard. It was to be designed for ease of documentation,
testing and management; documented to be maintainable over a life of 25 years;
structured to be as independent as possible of computer type and intercomputer
communications: and flexible so as to cope with modifications in service. Have
these criteria been met? Considerable advances have been made towards
meeting them. The quality of the software to meet long life standards is not as
high as anticipat' d and some re-work will be required to bring it up to the full
standards. The strategy of software testing was an area in which some
difficulty was experienced,particularly as regards the harnesses required to
ensure that adequate re-testing of software was possible after modifications
had been completed. The subject of software is discussed in greater detail in
Reference 10 which concludes that considerable progress has been made to meet
the high standards that were set.

With regard to the hardware, the design objectives here were basically
to produce to pre-production standards. This included full environmental
specifications, MOD equipment build policy and standards, with nuclear hardness
requirements. The processor and communication cards were supplied by the
computer manufacturer but all other cards had to be developed.

In general all the objectives were met except for some problems
experienced in availability and delivery of a number of highly specified
components, which resulted in concessions being given on them. As regards
ruggedness and nuclear hardness requirements, these were met, but with some
compromises on other targets such as size of units. With the benefit of hindsight,
it may well have been more prudent to have specified a lower quality of build,
bearing in mind the lack of experience which had been obtained on the processor
type prior to starting this Project. Problems were experienced with the
processor as regards its speed and memory size and considerable additional
effort was expended in trying to overcome these difficulties.

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The system objectives included the requirements, that it should control effectively a COGAG propulsion plant, that it should be easily installed on a ship, and that it should improve invulnerability. It will only be possible to assess fully whether these objectives will be met when the Demonstrator system is delivered and undergoes the series of tests planned at the Evaluation Centres, but certainly the early indications are highly encouraging.

Largely for the reasons set out in Reference 12, no attempt has been made during development to achieve large reductions in manning levels. Instead, by reducing the amount of information permanently displayed, by automating the logging of data and by providing information to the operators and maintainers in a more intelligible form, the R.N. is in a position for the next class of ship to:

(a) Make small reductions in the watchkeeping crew;

(b) Lower the qualifications of the watchkeepers;

(c) Make more effective use of its manpower.

Perhaps one of the most important aims was to achieve a highly flexible system that could be readily adapted to take account of changes in plant types. Again it is too early to assess with complete confidence how far the design succeeds in this respect, but it is significant that recently, when four different propulsion packages were being considered in early studies for a new class of ship, no undue difficulties could be foreseen in adapting the Demonstrator or PASS systems to interface with whichever type of plant was finally chosen.

Lessons Learnt

Even at this stage in the development of the RN systems, when much work remains to be done, and with evaluation activities still at an early stage, it is possible to identify quite clearly some areas in which a different approach should have been taken, and other areas in which it can be confidently stated that the early decisions were indeed correct.

Perhaps not surprisingly it is to the software field that one turns for the first important lesson that has been learnt. The software structure that has been derived for use in these applications is proving entirely sound, and a companion paper (Reference 10) describes the steps that are being taken to ensure the reliability and maintainability of this software. The implementation of the interprocessor communications software for the propulsion control system has, however, not been an easy task. The software overheads of the "core", or application independent software for the system, as opposed to the application software, have been higher than expected, and have led to problems of memory capacity in the hardware that was being developed concurrently.

A 2-7

For the next development, that of PASS, the decision was taken, as explained in Reference 9, to delay the choice of ship system hardware until the initial software development had been carried out. This enables the hardware characteristics, needed to host the software, to be defined with greater precision, resulting in a confident selection of the ship system hardware. This latter approach may very probably have an associated penalty in terms of development time, but experience shows that this is a price well worth paying.

A further software problem that has come to light is the danger of underestimating the task involved in controlling the issue of software, and in its support and maintenance over the ship's life. Although many of the tasks can be done manually with skilled labour, it is preferable, on grounds of cost and improved accuracy, to use a computer, where possible, and, indeed, a prototype system is now being used successfully on the PASS project.

Probably two of the most critical objectives in the whole approach adopted by the MOD were to achieve :

(a)   Software that was transportable, that is that could be run on a processor with a significantly different order code.

(b)   Hardware that was application independent and not tailored to a particular machinery configuration.

A foundation has been provided by the software approach taken, which makes it possible to build on the work already carried out for future Machinery Control and Surveillance Systems while being able to take into account the expected advances in hardware technology.

The success that has been achieved in both the hardware and software areas has given the MOD considerable confidence that a far better understanding of the technology now exists and that the main design objectives can, in fact, be met.

Conclusions

In designing systems for use in warships the importance of looking as far into the future as possible cannot be overstressed. The design on the drawing board today will probably be still in service 30 years or more hence, and the designer must therefore be bold in his choice of the technology that he intends to use, or else his systems will be obsolescent and generating significant support problems long before the end of the ship's life. Inevitably the use of advanced technology throws up problems not previously foreseen, but provided the ground is carefully prepared, then the rewards for striking the right balance between an approach that is too adventurous and one that is over-cautious can be considerable. The RN has opted to use the microprocessor in a distributed configuration for the control functions and to specify a separate computer for the secondary surveillance function. Much work yet remains to be done but there are no known major barriers in the way of achieving a powerful and highly flexible set of machinery control and surveillance systems using this approach.

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Machinery Spaces

Bridge   Ship
         Control
         Centre
         (SCC)

PCU — Plant Control Unit

SCU — System Control Unit

MMI — Man Machine
      Interface
      (i.e Displays &
      Operator Controls)

MMI

SCU

MMI
PCU

MMI
PCU

MMI
PCU

MMI

Console
MMI

GT   Gearbox   GT

MMI
PCU

GT   Gearbox   GT
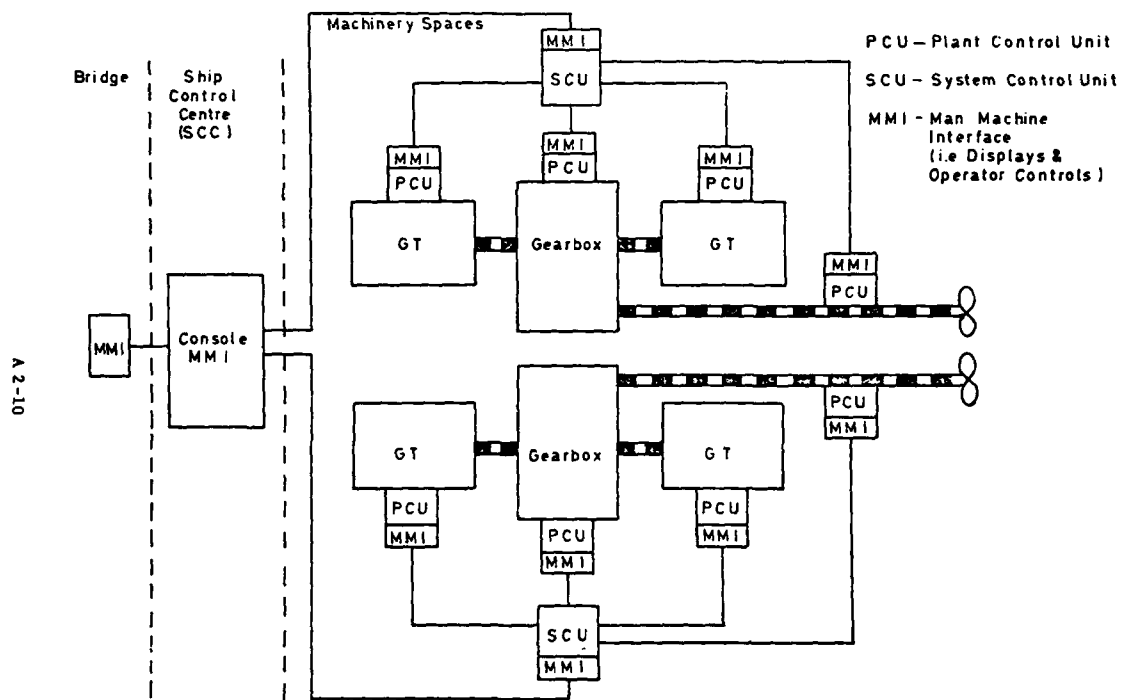
PCU
MMI

PCU
MMI

PCU
MMI

PCU
MMI

SCU
MMI

Figure A   Reference Propulsion Control System

AN R&D PERSPECTIVE OF U. S. NAVY CONTROL NEEDS
AND AUTOMATION OPPORTUNITIES

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ABSTRACT

Based on the premise that the U. S. Navy's primary needs in ship design are
subject to various trade-offs, the benefits to be derived from state-of-the-art
automation technology are examined. A brief history of naval machinery control
and operation is presented including recent developments in technology. The role
of research and development is examined in relationship to satisfying the current
and future needs of Navy ship design. This examination illustrates the advantages
achievable in the areas of construction, upgrading, systems integration, decreased
reaction times, manpower utilization, equipment availability and information flow.
A digital data bus multiplex approach is discussed as a logical catalyst to effect
total shipboard interface standardization for signal transmission. This approach
could bring about a major beneficial impact on the way naval ships are designed
and the way their subsystems are integrated.

INTRODUCTION

During the period since World War II there have been many changes in the con-
trol and operation of both navy and maritime ships. For the most part these
changes did not start taking place until the 1960's. The major advances came in
the merchant fleet first, where economy was a prime motivation--profits were being
eroded by higher costs, mainly for manpower. The 1970's saw a steep rise in these
advances as energy sources became scarce, which, coupled with inflation, caused
significant increases in operational costs. The U. S. Navy was also affected by
these forces and by changes in personnel resulting from an all volunteer force.
Reduction in manpower and more energy efficient operations became increasingly
important design goals. Early investigations and demonstrations showed where
automation applications could help obtain the desired results. In addition, the
adoption of the gas turbine main propulsion plant made some automation in these
areas mandatory due to critical equipment requirements. However, U. S. Navy
adoption of automation has not been rapid. There are numerous reasons for this,
but high on the list are real concerns over reliability and standardization, estab-
lished maintenance policies, damage control, military operational requirements,
and tradition.

U. S. Navy automation started with the incorporation of an automatic steering
device which had only limited success at first. Late 1960 designs included direct
throttle control from the bridge, and by the late 1970's machinery plant automation
was increased with the use of computer control and control station monitoring.
However, the equipment being produced actually represented early 1970 designs and
hardware due to normal shipbuilding lead times. Results in some cases were not
encouraging due to increased maintenance burdens, and increases in manpower and
skill levels to deal with this "new" technology. These problems led some to be
lieve that automation was required in gas turbine powered ships but not desirable
in other ships. From an R&D point of view, this was not startling information.
More RDT&E effort applied to the pre-shipbuilding phase would have uncovered
many problems before they were built into the ships. Insufficient attention to

reliabilit; and maintainability in early phases contributed to deficiencies of these designs and accounted for much of the problems.

The driving forces of increased costs of initial construction, manpower and energy, demands for timely and reliable information, and operational survivability should cause rethinking in the area of automation. New technology, processes, and hardware have put a new light on the incorporation of automation, where microelectronics (with super reliability), modularity (with greatly decreased maintenance requirements), distributed control, satellite communications, built-in-test equipment, better personnel environment, and automatic monitoring and trend analysis techniques will remove many of the drawbacks some see in automation.

BACKGROUND

Commercial

For many decades various facets of industry have automated their operations for two main reasons—economy and no other way to do the job. The oil, automobile, textile, electronics, and chemical industries are excellent examples of increasing automation. Generally, manual operations are slow, less accurate and less productive than automatic techniques. Some operations like electroplating, microcircuit manufacturing, and gas turbine control cannot be done by manual means and therefore must be automated.

Automation in the marine industry, unlike the aircraft industry which required automatic and remote control because of low aircraft manning levels and fast response requirements, has not progressed rapidly. Although autopilots were introduced in the mid-1920's it wasn't until after World War II that they began to be in wider use. More sophisticated equipment and operations did not begin to appear until the 1960's. These included remote throttle control, centralized engine control room, unmanned engine rooms, and the introduction of collision avoidance systems. The incorporation of these advances in technology was motivated by economy—where profits were being eroded by higher costs, mainly for manpower. Fueled by inflation and scarce energy sources, operational costs increased significantly in the 1970's causing a steep rise in technology advances being incorporated into ships. In 1979 the Third International Symposium on Ship Automation (ISSOA-79) was held in Tokyo where many of the new ship automatic developments and applications were discussed. In these discussions it was indicated that manning of large merchant ships has been reduced to levels of 18, with some test ships carrying only a crew of 12. For some a goal of 6 to 10 crew members is being pursued.[1] For the first time a guideline report on merchant vessel bridge layout has been prepared incorporating the latest in man-machine technology.[2] Studies have been made showing that fewer people are required during ocean transit than during coastal passage. This suggested crew reduction to 6 men with shore based crew when required.[1] These studies indicate that highly automated navigation and engine systems are required, with increased reliability over and above present levels. For ease of operation and increased maintainability, standardization of equipment and instruments is also required. In addition, the studies also show that these projected small crews may lead to loneliness and other mental conditions which will require serious attention.

Karasawa[3] surveyed much of today's merchant marine control systems and indicated that current unreliable navigation equipment is being replaced by the Navy Navigation Satellite System (NNSS). He said that collision avoidance systems are absolutely necessary; however, (if only one vessel in an encounter has a collision avoidance system) it is only a one sided assessment of the observed vessel's intended manuever. Two-way communication is needed in order to know the intent of the object vessel. He also suggests the incorporation of radio whistles and turning direction indicators. The survey indicated the requirement for failsafe and

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troublefree equipment which are readily maintained. New sophisticated equipment requires upgrading in reliability and maintainability due to reduction in personnel.

Orito[4] made some interesting observations relative to automation currently being developed. He found that standby engine room operation is the most labor intensive and must be automated as much as possible. Condition monitoring is desirable and there is a need for improved reliabiity--this is a prerequisite condition. He goes on further to indicate that if the reliability of shipboard machinery on the currently operating ships were adequate, it would be possible to man them with smaller complements without changing the specification of the ships. Orito recommended improved reliability for auxiliary systems, improved interior communications for reduced crew, automated navigation, TV monitoring systems, one man control wheelhouse, and a collision avoidance system. He said that his company had a container ship go to sea with some of these features in September 1979.

Ciundziewicki[5] indicated that automation was introduced in Poland in the 1960's. They have unmanned machinery spaces and automation in 100 percent of their ships being constructed today. This includes engine room machinery control and monitoring systems, electrical power generation, auxiliary systems, fire detection, bilge and watch control systems, and remote control from the bridge. Automation will continue as in the present, but no expansion is expected since owners are not interested. Some microprocessors will be used on a limited basis, and as microprocessors make automation more economical perhaps the owners will change their minds.

Other automation applications reported but too lengthy to discuss in this paper include: Spain[6]--auto correction path monitor; Turkey[7]--collision avoidance system; Russia[8]--anticollision system efficiency; Norway[9]--condition monitoring here to stay, dual processing systems--onboard and onshore, interplay between operator and system, automation to assist man--not his master--decisions more for man; Germany[10]--need continuous improvement in sensors for diesel engine automation; France[11]--steam plant automation.

Much of the "automation" that has been reported involves installation of collision avoidance systems. These are intrinsically automated systems but they do not automate the process of ship control. As presently designed and used they are only an aid to the operator. However, depending on reliability and operator acceptance they could make ship control (steering) an automated system--beyond the ability of present day autopilots. It is significant to note that there are more than seven worldwide manufacturers of collision avoidance systems, and as of mid-1981 more than 1400 systems were installed in merchant ships. Since the first systems were installed in 1969 there are many thousands of ship-years of experience accumulated. Operator confidence must be increasing or new installations would fall off--which is not the case. Further steps toward more automation are sure to come.

Another extremely important area associated with automation which is receiving much attention from researchers and designers is adaptive systems. With the advent of microprocessors much of this research has now become practical. At ISSOA-79, reports were given on numerous applications of adaptive systems. Kanamaru[12] discussed an adaptive autopilot to reduce propulsive energy consumption using simulation. Amerongen[13] described an autopilot for automatic trackkeeping for bad weather which incorporates adaptive feedback. Horigome[14] described an all digital autopilot which was built and tested onboard a ship; this system eliminated an extremely complex mechanical system. Ohtsu[15] reported on a noise adaptive autopilot tested at sea with excellent results.

U. S. Navy

The propulsion plants of U. S. Navy ships have been automated to various
degrees since at least World War II. Various level control devices and automatic
controls on air compressors and distilling units have been in use for years. In
addition, steam plants and diesel engines have incorporated various elements of
automation from the beginning.

The early 1950's saw the introduction of pneumatic automatic combustion con-
trol (ACC) and feedwater regulating systems. The mid-1960's saw the introduction
of complete propulsion plant automation systems for three classes of 600 psi steam
turbine driven auxiliary ships: Amphibious Cargo Ship (LKA 113), Ammunition Ship
(AE 32) and Combat Store Ship (AFS 4). Automation of these auxiliary ships re-
sulted in remote-operated, programmed throttle control and the centralization
of remote controls and data gathering necessary for plant operation. Included in
this design was the extension of the remote throttle control from the bridge. The
need for higher rated men, better trained and more highly skilled for operation
and maintenance was clearly seen at this time. Cross-training was advocated as a
way to yield Navy personnel as much as possible like their merchant marine counter-
parts.

As we entered the 1970's, higher automation levels continued with the intro-
duction of the steam driven auxiliary ships of the general purpose Amphibious
Assault Ship (LHA-1) Class and an Oiler (AO-177) Class. Two new combatants, the
Guided Missile Frigate (FFG-7) Class and Destroyer (DD-963) Class, both powered by
gas turbines, followed in the vein of the automated steam ships. This later auto-
mation generally included propulsion unit control, throttle control, main reduction
gear control, controllable pitch propeller control, air system control, fuel and
lube oil service system control, electric plant control and data handling.

In late 1976 a demonstration of the feasibility of achieving a reduction in
bridge watch manning and improving surface ship readiness and operational effec-
tiveness was conducted onboard the Frigate USS MCCANDLESS (FF 1078).[16] This
demonstration system was designated the Integrated Bridge System (IBS). The IBS
embodied the integration of existing bridge equipments and the introduction of
automation into a centralized work station for bridge watchstanders. The IBS
consisted of two major consoles and peripheral bridge and remote equipment.
Incorporated in the system were communications (sound powered phones, ships' alarms
manned and ready system, and external voice communications), ship control (auto-
pilot, hand electric and non follow-up steering system, and a modified engine
order telegraph—limited by the existing non-automated power plant), manuevering
and navigation (radar display, collision avoidance, digital charting and maneu-
vering board solutions), logging (data logger, voice recorder and digital recorder),
and other items such as alarms, an automatic Omega navigation system, a weapons
advisory panel, overhead centered pelorus and controls for all navigation lights.
This feasibility demonstration showed the opportunity for reduction of bridge
watch manning while maintaining or improving operational effectiveness during the
evaluation period onboard MCCANDLESS. However, incorporation of IBS type systems
in new U. S. Navy surface ships has not taken place.

A follow-on system to the IBS designated HICANS (High Speed Collision
Avoidance and Navigation System) is under joint development by the U. S. Navy
and Sperry Systems Management for the Guided Missile Patrol Combat Hydrofoil
USS PEGASUS (PHM-1). The HICANS is presently undergoing at sea testing. De-
tails of this development are discussed by Puckett[17] in this symposium.

Past Motivation

The factors that led to an increase in automation were for the most part
rather obvious. ACC for steam plants was being incorporated more and more into

merchant ships with demonstrated manpower savings. The U. S. Navy sought the same economical benefits. Automation also promised better fuel economy, faster response, better control and more efficient operation. The primary motivating factors could be summarized into two general categories: (1) it would be more economical in the long run, and (2) response time required could not feasibly be supplied by human operators. From this evolution of shipboard automation the U. S. Navy finds itself in a situation where some very serious questions are being asked.

NAVY AUTOMATION - SOME DIFFICULT QUESTIONS

From the authors' viewpoint it appears that the U. S. Navy is questioning its involvement in automation for a number of practical reasons. In practice manpower savings are not being realized. Where comparison of automated and nonautomated ships can be made, essentially no difference in manning levels is evidenced. Furthermore, the automated ships require a higher caliber of personnel with extensive training to operate, troubleshoot and maintain these more complex systems. To date, these automated systems have been more costly to purchase and there is mounting evidence that their maintenance costs are outweighing their nonautomated counterparts. With heavy maintenance burdens being placed on a limited number of qualified personnel, commercial vendors are being called upon more and more for much of the equipment maintenance, repair and grooming. When this equipment doesn't function properly, it is necessary to resort to the manual backup modes. Because of the above operational experience, many expensive automated systems are being operated in an unplanned labor intensive manual backup mode. Coupled with the above manpower demands is the manpower required for the ship's normal preventative and corrective maintenance, sea duty, and personnel training. As mentioned earlier some have raised the question of "Wouldn't we be better off without automation?"

It is generally conceded by even the most critical opponents of automation that it does provide faster response, better control and more efficient operation when it is functioning properly. Nevertheless, some of these systems that have been incorporated to date cannot be counted on to be available when needed. Where speedy response is a critical requirement, redundancy can be used to provide sufficient availability, but conventional redundancy is unfeasible across the board. Economical life cycle costs with all that they entail (procurement, operation, maintenance, training, logistics, etc.) together with speed of response will continue to be prime automation motivators for U. S. Navy designers.

Consideration of these prime motivators leads one to examine more closely what they entail. The increasingly sophisticated threat environment will demand increasingly sophisticated system complexity and inter-system information exchange. More shipboard personnel will demand more information. Commercial suppliers upon whom the Navy must rely will be producing automated equipment to remain competitive in the commercial arena. Pressure from industry to adopt increasingly sophisticated automated systems is becoming greater every year as controls technology advances.[18] Therefore, the Navy will be forced to select equipment from this new equipment of commercial suppliers or purchase costly custom designs. The pace of technology will increase such that shipboard equipment upgrading will be taking place almost continuously. The ships will have to become more survivable from weapons threats. There will be a proliferation of sensors, computers, communications equipment, electronic warfare systems' countermeasures, rapid response weapons, and navigation systems in future ships. These systems produce incredible masses of data and techniques must be devised to extract critical information quickly. At-Sea Commanders must be provided with capabilities for the automated receipt, storage, exchange and use of tactical data including that from off-board sensors.[19] In an address to the American Society of Naval Engineers H. Tyler Marcy, while he was assistant Secretary of the Navy for R&D, indicated the need to transfer as many of our recent technological developments into our new ships as is possible.[20] In this address he used the AEGIS Combat System as an example of technology application as a major step forward. Dr. Richard DeLauer[19] stated in

an address to the American Society of Naval Engineers that of all the areas of technology in which the United States has established and demonstrated its superiority, the area of automation will almost certainly provide the greatest leverage on the productivity of our military capabilities. However, it must be remembered that the mission of a Navy Combatant ship is more complex than that of a commercial ship and the consequences of unreliability can be much more drastic.[21] Finally, will we ask that the operation and maintenance of these equipments be placed on generally unskilled, and overworked operators/maintainers whom the Navy can ill-afford their time away from the ship for training. Where do we go from here?

FUTURE OPPORTUNITIES

Technological Applications

In a recent study[22] King concluded that consideration must be given to the substantial influence of computers in the areas of monitoring, controlling, and information handling. The number of people onboard can be reduced to a very small number-the unmanned commercial ship is a practical possibility (Une[1] defines an unmanned ship as one with 6-10 man crew). He also indicated that all routine monitoring must be done automatically. He pointed out that technology innovations should enhance human capabilities rather than make them redundant. Computers can replace some of the skills of men, be a tool for men to use, and provide new tasks for seafarers, however there is a need for a greater awareness and understanding of ships as socio-technical systems.

Recent experience by the Royal Navy[18] shows that automated data handling systems for track sorting, target identification, and routine processes involved in compiling the tactical picture has acheived significant reductions in number of men required in the Operation Room.

The importance of the work being performed in automatic control prompted the holding of the Symposium on Ship Steering Automatic Control in Genoa in June 1980. Extensive theoretical and experimental investigations of control, adaptive control, autopilots, etc., were discussed and published. Some of the areas covered were: Hopkins[23]--adaptive autopilot to prevent leeway where autopilot navigates the ship; Kasahara[24]--optimal steering control systems; McIlroy[25]--reduce pilot workload with optimal control computer aided steering used with precise navigation system; Coleman[26]--adaptive steering model tested at sea; Bouthianon[27]--using sophisticated control laws for the autopilot for the Tripartite Mine Hunter.

Application of the state-of-the-art in automation is illustrated by a recent advertisement for an automatic steering system which also works in turning maneuvers and has built-in test routines that do not require knowledge of computer techniques. In addition, a joint venture of the French, Belgium and Netherland Navies involves incorporation of a digital autopilot for the "TRIPARTITE" Mine-hunter which uses sophisticated control laws for guiding, piloting and controlling. The imminent implementation of this system can be considered a significant application of shipboard automation.[32],[33]

Digital data buses as embodied in the U. S. Navy's Shipboard Data Multiplex System (SDMS)[28] and the Canadian Forces' Shipboard Integrated Processing and Display System (SHINPADS)[29] offers a capability that can be exploited by permitting the incorporation of new automation technology by U. S. Navy ship designers. It is estimated that the DD-963 has 800,000 feet of cabling at an installed cost of $40/ft.[28] The application of the SDMS concept is conservatively estimated to reduce the cabling installation cost of a like ship by 35 percent. That's a savings of over $11 million per ship. Greater savings can be expected on newer ship designs that will undoubtedly become more complex. Add to this the benefits of never having to rewire because of installation of new equipment, changes in threat, and new subsystem technologies and the cost savings continue to mount.

A major consideration in the Canadian Forces SHINPADS and indeed their recent destroyer designs is the issue of NATO standardization. The work of NATO group NIAG SG 6 regarding interface standardization was an integral part of the SHINPADS design. The criteria as applied required all devices to plug into the system via NATO interfaces as proposed by STANAG 4153.[30]

If we use the analogy of SDMS to a conventional telephone network with the appropriate interface terminals we get a better idea of the benefits of SDMS. The benefits of standardization become readily apparent. Individual shipboard equipment designers can proceed more at their own pace with less pressure to prematurely freeze designs for system integration because they need only "plug-in" at standard interfaces at the appropriate time. Here again a potential[29] costs savings is realized by eliminating the need for expensive contract modifications after detailed design begins.

The interface terminals addressing the data bus not only provide the standardization so desperately needed but also provide for a multimission controller/display station. For example, the same station can function not only as a propulsion control unit but also as a distilling plant energy-conscious controller where, with the push of a button, its function can change from one to the other. This relative ease at reconfigurability will provide post-hit damage control and equipment survivability benefits. The information flow whether from one compartment to another or from one end of the ship to the other is on the common buses. In fact, the greater majority of data traffic onboard the ship will be on the buses. Here again another benefit surfaces. This benefit revolves around the increasing demand for more and more information by more and more parties. Most of the data generated onboard will be available on the bus and informational display packages can draw on this data to provide predigested information to whomever needs it.

So far most of the prime motivators for automation have been addressed but perhaps the question of reliability should be further expanded. If the telephone industry can make communications networks reliable, standardized, modular, and general purpose throughout the U. S. and the world, certainly the Navy should be able to do it on one ship.

The U.S. Navy's SDMS specifications require a reliability of 0.999 for any single user circuit that is implemented over a 24-hour period. A system reliability requirement of 0.99999999 over a 24-hour period with no repairs is also specified.[31] Minimal mean time to repair and applications of redundancy can further enhance these design requirements. Since the SDMS will be a system upon which all subsystems depend, it is important that the above reliability requirements be demonstrated. Landbased facilities are already in existence to fully test and demonstrate the SDMS development model. Incorporation of a system, such as SDMS, into ship design should provide for almost limitless automation opportunities.

Certainly if industry wants to see wider acceptance of automation in the marine community, it will have to assure that required skill levels for operation and maintenance are lowered, that reliability is increased, and that mean time to repair is reduced. The important point is that this is a requirement of not just the components (e.g., microcomputers, integrated circuits) but for complete systems in their final environment (relative location, temperature, humidity).

From our viewpoint the major challenge for R&D is to make new technology useful and dependable for the ships' forces. If the automation isn't user-friendly, we're just providing an already overworked operator an additional heavy burden.

R&D Opportunities

As previously stated the prime automation motivators for the U.S. Navy will continue to be life cycle costs and speed of response. It should be noted that

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these two areas encompass: training, maintenance, standardization, modularity, energy savings, control of complex systems and manpower (reduction, skill level). From an R&D viewpoint these motivators represent opportunities which must be seized to exploit automation for its maximum benefits. Four areas into which these opportunities/benefits can be divided are as follows:

I. Decreased response time for situations where manual response can't be tolerated or where complex decision/control processes are beyond human capabilities. Modern weapon systems and the ships that carry them must operate in a fast moving scenario. Response times for ship systems have become very short. For example automation is required to operate and control the main gas turbine propulsion plants to carry out required actions that are too fast for response by humans. Less than this cannot be tolerated or catastrophic failures could occur. This application of automation will become even more necessary if combined propulsion and ship service electrical and electrical propulsion systems (now being given serious consideration by the Navy) are incorporated into new ship designs.

The exclusive use of voice methods to exchange information on aircraft carriers is causing communications traffic to approach critical proportions between work stations, especially during emergency conditions. Officers are becoming overloaded and delays and misinterpretation of information due to overcrowding and high ambient noise levels is becoming more common. In this area, electronic methods to exchange information between work stations could replace the present sound powered, status-board method used for exchanging aircraft launch and recovery information, aircraft position information, weather and "BINGO" data and other status information affecting safety of operations. The associated record keeping tasks currently performed during air operations and primary flight control can also be provided by electronic means. [34]

A modern Navy ship is a complex mixture of men and machinery. It is a weapon, a hotel (food, sleep, laundry), a vehicle, a hospital, a warehouse, a telecommunications center and a recreation facility. As such, the quantity of information, record keeping and decision making will require computers to monitor, store, sort out and display relevant information for timely decisions. Systems will have to be developed that allow for selective display of information, sharing of information among various ship subsystems, and the ability to be interrogated by the user. A major challenge to the R&D community will involve fitting these machines to the man instead of vice versa.

It should be noted that human operators by nature are generally ineffective at monitoring steady state equipment parameters and quickly become bored. At the other end of the spectrum the human operator is subject to errors in stressful situations. In addition, the human operator is not ideally suited to environments involving high heat, humidity, noise or nuclear or chemical contamination.

From the authors' point of view the only possible reservation with automation should be that automated systems be extremely reliable with high availability and that the users/operators have confidence in the automated systems. Recent experience on some systems has been poor and the automated systems had to be removed because of lack of availability. There is an opportunity here to capitalize on technologies that are available now. Research and development to identify problem areas and demonstrate highly reliable systems is required. Full scale landbased simulations are required with quantitative techniques for measuring system reliability. System availability is critically important _after_ the systems are arranged in their _final_ ship configurations.

Reliability statistics in terms of component failure rate data are viewed by many with much skepticism. In fact, Dogan[21] suggests that specifying ultra-high reliability by MTBF's is inadequate and perhaps probability of mission success over finite time periods would be more meaningful, especially on a system basis.

A 3-8

For example, he indicates an Air Force digital avionics information system failure rate of 10^{-7} failures per hour should be stated as a mission probability of success of .999 999 7 for a 3 hour period. A commercial avionics requirement of 10^{-10} failures per hour in digital control systems should indicate a success probability of .999 999 999 for a ten hour flight.

Navy ships have longer mission times and repair is possible, which confuses the issue considerably, but the same concept could apply. It appears that the Navy's task should concentrate not so much on hardware reliability but on system architecture, system software reliability and meaningful system reliability specifications.

II. Standardization, modularity, and multipurpose interactive displays with access to any and all data to simplify the man-machine interface problem. Some of the major problems today and projected in the future are high acquisition costs, high maintenance, and high skill levels required of operators and maintainers. With the advent of microelectronics and digital technology, a large variety of electronic operations can be modularized, and standardized assemblies are being made. Efforts are also underway to establish the requirements for mechanical modularity and standardization. Standardized, modular systems will reduce the cost of spares, simplify maintenance procedures, reduce the cost of maintenance because the number of different components are reduced, and reduce skill level requirements because modularity will permit many more repairs by replacement. Standardization and modularity should lead to increased reliability and decreased maintenance burden, and thus, provide the needed increase in availability.

The automation opportunities afforded the Navy in this area will depend heavily upon the incorporation of a standardized digital data bus multiplex system, such as the U.S. Navy's SDMS or the Canadian Forces' SHINPADS. Once this system and its interface modules are standardized, multipurpose displays and controllers can be standardized. Research and development efforts will be required to assure flexibility is maintained in these standardized displays and controllers. The multipurpose aspect will require shipwide analyses of the multipurpose functions required. One approach could be retaining flexibility in software while committing the hardware to standardization.

Great care should be taken as to how much information is displayed at one time, since human operators have limited capability for assimulating information and can quickly become overloaded. Multipurpose visual display units can be used to display what is desired or required. For example, an operator monitoring the status of the propulsion and steering functions may not want to know main bearing temperatures, lube oil temperatures and pressure or vibration levels when everything is working properly. However, when a fault condition occurs, this information could become vital.[35] Equipment is available today to perform this function.

Digital display systems, both electronic and solid state permit operator interaction in order to allow for mult'purpose information access on all systems. The displays can provide information for decision making and also be used as a control input device.

Research and development efforts are needed to evaluate the benefits and point the way for shipboard applications in such areas as using color for displays, bright screen displays for bridge use, making displays multipurpose but simple, and developing a maintenance philosophy based on standardization and modularity.

III. Cost effective redundancy achievable through distributed control. Present technology, mainly as a result of highly reliable and relatively inexpensive microprocessors, involves a variety of applications of distributed control throughout industry. It is possible to design standardized, modular processors inexpensively, permitting their widespread application in different systems. In addition

redundant systems can be designed in order to maintain high system availability in the event of a casualty. This will permit using alternate paths inherent in a distributed control system to circumvent failed or damaged equipment. The navies of several countries are investigating the use of these distributed systems. This is an opportunity that doesn't have to be made or found. It is here. However, research and development will be necessary to implement the most cost effective options to suit Navy missions. Coupled with data bus techniques new concepts should consider this new technology to reduce costs of redundant systems, provide more system flexibility, and provide the ability to reconfigure for casualty control.

IV. Non-interference onboard training of the crew accomplished both at dockside and underway. As a result of the availability of inexpensive microcomputers, digital simulation techniques, and multipurpose interactive displays new and effective training tools are available. At dockside, using simulated scenarios the ship can be made to appear to perform many emergency and out of the ordinary operations and provide for non-interference training. Training rooms can be made available with interactive displays to provide a continuous learning capability. Even while at sea, the simulation techniques can be used to train the crew in many types of emergency situations both in the machinery and bridge areas. Encompassed in the computer data base can also be the step-by-step troubleshooting and maintenance instructions. The opportunities here appear to be boundless. Development of new training philosophies and evaluating new training on simulators is required to make optimum use of this capability.

CONCLUSION

It was the intent of this paper to present an R&D perspective of the automation opportunities available to the U.S. Navy. The picture that materializes is one of complexity, rapid change and diversity. As can readily be inferred from the foregoing examples of the many R&D automation "products" being generated, there appears to be an endless supply. The fact remains, however, that this technology push doesn't always line up with the requirements of the normally conservative buyer.

The major challenge to the R&D community appears to be developing a more effective methodology for phasing new technology developments into long term development requirements. In other words, increased attention has to be paid to a more focussed automation technology procession by the R&D community in order that Navy ships of the future will be both cost effective and mission worthy.

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REVIEW OF DIRECTION AND SPEED OF THE ADVANCE IN
SHIP CONTROL SYSTEMS

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INTRODUCTION

In this article some critical remarks are made about the design
and application of ship control systems. Firstly, the criteria for
the application will be discussed. Secondly, the sequence of the
various steps in the design phase are investigated. Thirdly, the
research in relation to the complexity of the system is discussed
including the status quo in the Netherlands.

CRITERIA FOR APPLICATION

Before a decision about the application of a control system on board
ships can be taken, five criteria have to be considered:
- Does the application improve the working conditions of the man
  on board?
- Does the application lead to a more efficient use of the
  available manpower?
- Does the application improve the availability of the ship?
- Does the application decrease the maintenance cost of the ship?
- Does the application decrease the operational cost of the ship?

The authors strongly believe that criteria for the application of
a "beautiful control system" have sometimes been contrived to enable
the application of a newly developed control system. The decision to
apply a control system should not be taken before the advantages of
the application of the system are obvious.

DESIGN SEQUENCE

To obtain an optimal ship control system much effort should be
put into the management of the designers. The science of control
engineering is a relatively new one, so some rather important steps
that should be taken in the right order, are sometimes taken too late
or, some steps are even totally neglected.
Ten different steps that should be taken, can be seen; the correct
order of the steps, however, depends on the nature of the system to
be designed.

The objectives, including the essential data.

Although it sounds simple to establish the objectives and the
essential data, it is very often the most complicated phase of the
design process. The objectives should be optimalized in order to get
a cost effective system. Collection of the essential data is not
complicated; the main problem is to distinguish which data are essential.

A 4-1

Modelling of the control system.

In order to design an optimal control system, a model of the system is indispensable. The design philosophy of the control engineer and the professional engineer (naval architect, electrical engineer, etc.) differ a lot. It is generally accepted by scientists, who are not involved in control engineering, that a mathematical model can be very complicated. The control engineer though generally settles for a simple "black box" model, which usually turns out to be adequate.

Simulation and sensitivity study.

As soon as the mathematical model of the process and the control system have been established, the process can be simulated. The sensitivity of the various co-efficients should be investigated, to detect which co-efficients can be neglected.

Requirements.

The requirements can be obtained from the simulation study to make the system as cost effective as possible, the requirements should be limited to the absolute minimum.

Market analysis.

Many control engineers tend to prefer to design their own special purpose control system as opposed to buying a general one. As a result the system applied is very often more expensive than a general purpose system, and it is also more complicated to service.
A thorough market analysis should be considered together with the fact that a general purpose system often will be less expensive than a specially designed system.

Prediction of   - investment
                - operating cost
                - effectiveness
                - reliability

These four items define the final success of the application of the system.

Production and installation of prototype.

Checking of performance.

The performance should be checked and compared with the mathematical model, the simulation and with the prediction.

Final production and installation.

Continuous analysis of the system.

During the operation, the system should be checked continuously, to gather the necessary information for improvements to future systems.

THE RESEARCH IN RELATION TO THE COMPLEXITY OF THE SYSTEM.

Scanning through the papers of all the ship control systems symposia, including this 6th SCSS, it is noticeable that almost all papers are dealing with sub systems.
This may seem remarkable, but indeed it indicates the trend in ship control research. Research in sub system control subjects seem to be popular and of interest to the researcher. The fleet manager, however, ought to realize that research into fleet control and so into integrated systems is more effective. Nowadays, a tremendous amount of effort is spent relatively on sub system control, but little effort is put into the control of the whole ship and the effort spent on the control of a whole fleet is almost negligeable.

Let us glimpse now at the status quo regarding ship control systems research and application in the Netherlands.

Before presenting you this picture, it is perhaps good to realize that in the Netherlands also, the development of technology is greatly affected by our fast changing society and the consequences of the drastic changes in energy policy since the 1973-crisis.

In ships of the Royal Netherlands Navy and the Merchant Navy more and more control systems are applied as a result of the technology push and the push is reducing ship's crew members.
However, a certain reluctance to use more and more automation can be observed, especially in the Merchant Navy, as reliability of control systems on board seagoing ships still seems too poor.
Of course manufacturers of ship control systems claim that their system is very reliable, but practice shows different results. Also, quantifying figures are very difficult to obtain especially regarding mechanical components.

The Navy is still launching a new generation of GT-frigates. Development and design of the control systems of these ships are in the final production/installation and "feed back" stage. Efforts are now focussed at:
- amelioration of and integrating the sub systems
- standardising and
- computerising the operational availability of a total ship and fleet.

As far as the Merchant Navy is concerned, a milestone was reached in 1979. At that time the government, shipowners, shipbuilders and Union(s) -as participants in the organization of the Netherlands Maritime Institute- initiated the so called "Ship-80 project". The main objective of this project is: "to draft directives for the design of rationalised ships for the 1980's".
The rationalization is specifically aimed at the
-adaptation of the number of crew members to the changing economic and social circumstances
-minimizing and control of maintenance
-minimizing energy needs of the ship and its sub systems
-minimizing production and shipbuilding costs.

The project will be completed by the end of 1981 and is divided in two phases. About 175 spec alists (mainly part-time) are involved in the realization of the project. The approach is, in our opinion, rather new: a total integrated systems approach.

A 4-3

Figure 1. shows the working scheme of the project. Three lines can be identified, namely a technical one, an operational one and a financial/economical one. To realize the technical analysis the ship has to be divided in modules (sub systems). At the end all the studies have to be integrated. Up to date experiences indicate that a number of tools we have to work with, are not adequate enough. The reason is obvious: science of a number of branches for the shipping industry is still at an inadequate level.

Research institutes and universities in the Netherlands are working on problems mainly associated with sub systems. For example: ship manoeuvring, motion control, vessel traffic in harbours, propulsion machinery, all using mathematical simulation models. Adaptive autopilots and application of human engineering are also still subjects of research.

In conclusion, it must be stated that there is a tendency to look more and more into the direction of the control of the integrated system.

The general situation regarding ship control systems research efforts can be visualized in figure 2a, b, and c.

From figure 2 can be derived that too much effort is spent on the sub systems. Research into sub systems is not as complicated as research into the integrated system. It should not take years before a useful result can be achieved. It should also be realised that it is much more effective to increase the reliability of an integrated system, i.e. a whole fleet than to increase the reliability of all the different components of the fleet.

As can be seen from the status quo of ship control systems in the Netherlands, the Navy and those who are involved in shipping industry, -in a modest way- are trying to fill the above mentioned gap in research.

CONCLUDING REMARKS

Supposing that the presented papers and publications of ship control systems are representative for the direction and speed of advance in this field, it must be stated that the results of 15-20 years of research are rather poor. We have to keep in mind that technology has to anticipate the fast changing structures and demands in society. This can only be solved by thinking in conceptions of developments of systems.
So the authors are of the opinion that much more effort should be spent in research in integrated systems - there is little time to fulfill this goal.
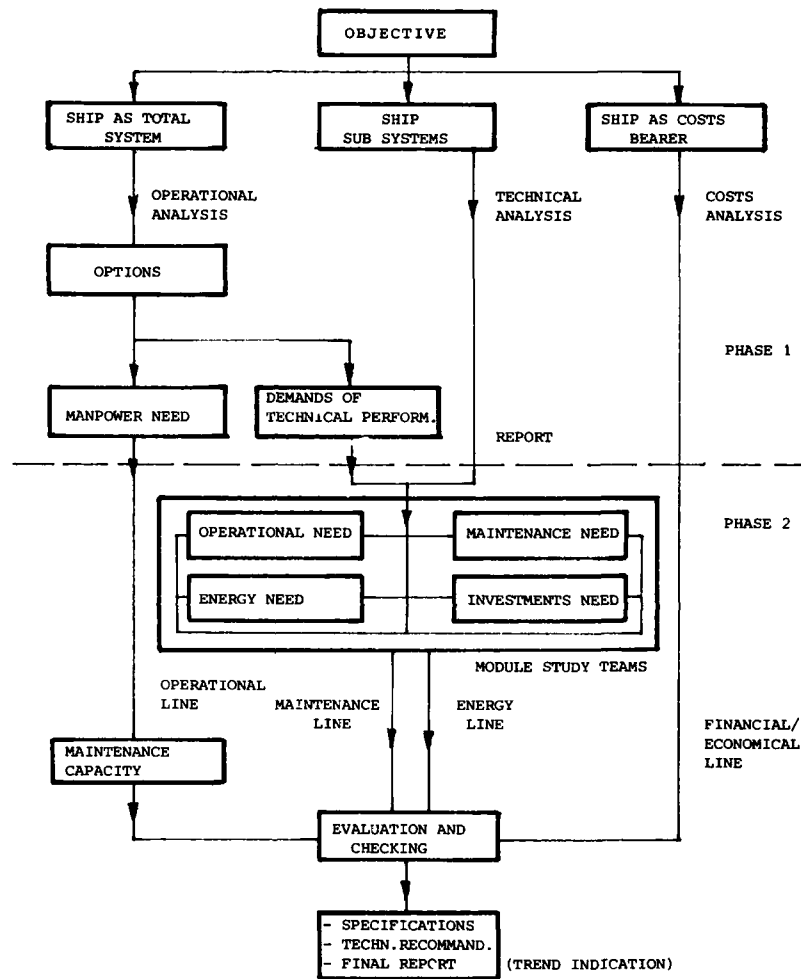
Figure 1. Working scheme project "Ship-80"

A 4-5

integrated system

FLEET

SHIP

sub system

"Topo"-diagram

needed effort rate

research effort rate
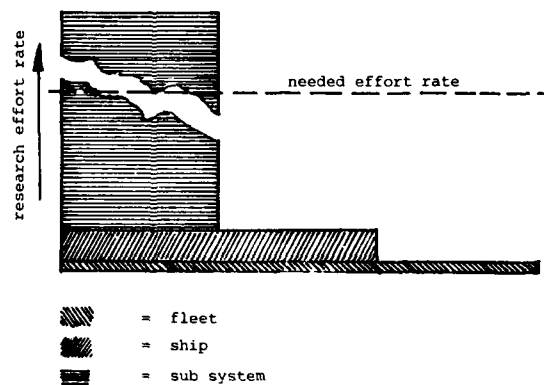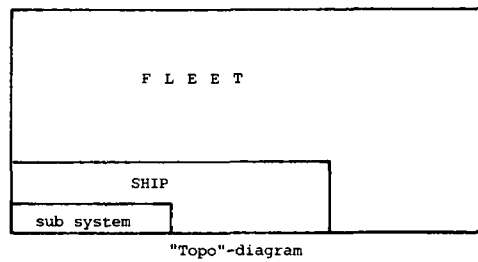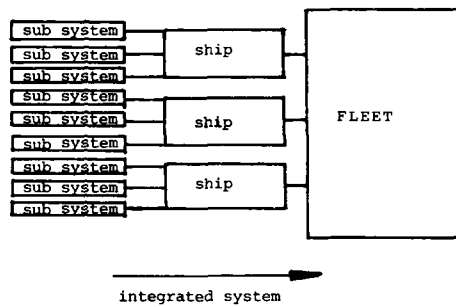
- 〰 = fleet
- ▓ = ship
- ▆ = sub system

Figure 2.
A 4-6

MACHINERY MONITORING SYSTEMS

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ABSTRACT

A distributed microprocessor machinery monitoring system has been
designed and built, tailored to significantly reduce the watchkeeping
task in the machinery spaces of naval vessels. The structure of the
evaluation system is outlined indicating the operational advantages to
the watchkeeper. The lessons learnt from design and development of
this evaluation system are examined and a revised system is described
which uses the experience gained. Finally, the manner in which the
collated data at the central station can be used in terms of Health
and Trend analysis are reviewed.

Introduction

The machinery Monitoring Systems dealt with in this paper were
developed in response to a Statement of Requirements for a Group Warn-
ing System.(Ref 1), as part of an overall contract from the Ministry
of Defence (Procurement Executive). The original hardware concept was
based upon maximum commonality with the Distributed Control System,
which forms the subject of a separate paper at this Symposium (Ref 2).

Both of the systems described are specifically configured to meet
the requirements imposed by conditions existing in machinery spaces.
However, this attribute makes such systems ideally suited to any moni-
toring application when physical size, high ambient temperature and
dirty environmental conditions preclude the use of "standard commer-
cial" systems.

In this paper, the general topic of monitoring systems will be
dealt with in four parts.

(a)   The Group Warning System Concept.

(b)   The Evaluation System produced for Vickers Shipbuilding
      Group Ltd.

(c)   The lessons learnt from the Evaluation System and present
      developments.

(d)   The indirect benefits gained from the ability to carry out
      Health and Trend analysis.

The direct benefits gained from the installation of any distri-
buted monitoring system in terms of reduced manning levels and lower
installation/cabling costs have been well aired in earlier symposiums.

The Group Warning System

The concept for the Group Warning System evolved out of the need to reduce the numbers of crew now involved in watch keeping tasks in machinery spaces. The basic hardware structure is based upon time proven data logger principles. The "System" differs from data loggers in two important aspects. (Fig.1)

(a) The data collection from the source transducers is configured around the use of distributed microprocessors, which in addition to the data collection function, provide the ability to compare input values with preset limits and generate warning flags for those channels exceeding the limits.

(b) The data from all input channels is collected at a single point and collated into Machinery Groups. This is where all signals related to a single piece of plant, regardless of their geographic origins, are collated to drive a single back lit legend, termed a Warning Window. Thus in the event of any plant malfunction, the watchkeepers attention is immediately drawn to the relevant system. Back up information in terms of the actual parameter and its value against its limit is simultaneously provided on a VDU. Secondary benefits are that the watchkeeper may view the current value of any parameter without moving from his position and that all warnings are logged automatically relieving the operator of this monotonous chore. Inhibit facilities to prevent unwanted warnings from shut down plant or faulty transducers are also provided.

The Evaluation System

The basis of any distributed monitoring system is a Central station, or Master unit, and an outstation which is repeated to match the number of channels it is desired to monitor, and their geographic locations. The primary requirements for the Evaluation System are shown in Table 1.

Table 1   System Requirements

1)   1000 input channels.
2)   1 second update rate for all channels.
3)   Integral signal conditioning for standard hardware.
4)   Multiple fallback modes.
5)   Structured software.
6)   Nuclear hard capability.
7)   Extended temperature operation.
8)   Rugged construction.

An Overview The hardware/software structure of the Evaluation system was based upon the work done on the development of the Digital Distributed Control and Surveillance System (Reference 2).

B 2-2

GROUP WARNING SYSTEM CONCEPT

Serial Data Link
To optional surveillance
processor

| Optional Printer |
| Group warning windows (100 max) |

CENTRAL STATION

Primary Display (VDU)

secondary display (MMI)'

Serial Data Link

MMI Panel

OUTSTATION (one of twenty)

Plant Inputs
(100 Max)
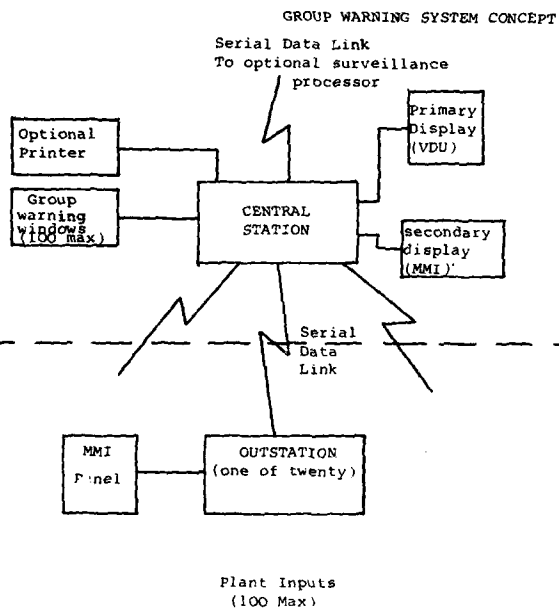
The Central Station provides:-

1) Correlation of channels in to Machinery Groups.

2) Operator "alert" for any channel exceeding its limits.

3) The operator with full information about the channel in warning.

4) The ability to view the current value of any channel.

The Outstation provides:-

1) Full signal conditioning for 100 inputs.

2) The scaling of inputs into engineering limits.

3) The comparison with preset limits and warning generation where required.

4) The facility to inhibit unwanted warnings for example from disconnected transducers.

5) The final fall back position for the operator in the event of failure of other parts of the system.

Figure 1. Group Warning System Concept

B 2-3

The hardware, comprising a set of electronic plug-in modules, has been designed for operation in ambient temperatures of up to 100deg C and to withstand the shock levels which may be experienced in Naval environments. All devices chosen in the design of these modules have been selected to ensure that the system as a whole is resistant to the radiation levels likely to be experienced in a tactical environment.

In order to ensure the maximum flexibility of the hardware, the computer bus configuration was adopted whereby all of the interface modules, whether they be plant interface or serial data links to other processors, are connected directly to the computer highway.

The data links used for the transmission of data from the outstations to the central station are high integrity, high speed serial links using the Ferranti Serial Signalling System protocol. These data links are star connected for maximum overall system reliability without recourse to the complication of duplicated links.

The software used in the system is fully modular, running under the MASCOT operating system. The software has been split into two parts, The Systems and the Applications code. Whilst this causes some increase in the overheads, and therefore the software runtime, this gives the advantages that the system may be configured to a new application by merely compiling new sets of parameter tables.

Further details of the hardware and software formats can be found in reference 2.

The Outstation The outstation comprises five modular units (fig.2) mounted in a cabinet of 12u (21 inches) height. These units are:

(a) The card frame containing all of the electronic modules. These modules cover the functions of the processor, volatile and non-volatile memory, serial data link, and all signal input and display output functions.

(b) The filter unit which provides full Radio Frequency Interference and Electro Magnetic Pulse protection for approximately 280 input lines, with a plug break between the filter unit and the ships cabling. This plug break allows the outstation to be installed much later than is normal in the vessel build program, after all of the ships cabling and transducers have been installed and checked.

(c&d)The Transformer/Rectifier Unit and the Power Supply Rack. A 440V 3 phase supply is used to gain the advantage of transformer isolation without the bulk of smoothing components associated with the use of a single phase supply at the required current ratings. The power supply rack provides the necessary d.c. voltage rails with over voltage/under voltage protection and the cooling fans.

(e) The Man Machine Interface unit, (Fig.3) which in addition to providing the Operator with the final fall back position, in the event of a data link or central station malfunction, also provides the Maintainer with the ability to reconfigure channels to match in-service requirements. This may be achieved at short notice and without specialist help. The important operator facilities provided locally to each outstation are:

B 2-4

Figure 2 Outstation Block Diagram

Text within the diagram:

- SHIPS CABLES
- EXTERNAL JUNCTION BOX
- 440V 3 ph
- 8 cables 330 wires
- TRANSFORMER/ RECTIFIER UNIT
- PSU/FAN RACK
- RFI/EMP PROTECTION
- 1 cable 25 wires
- 2 cables 70 wires
- 8 cables 330 wires
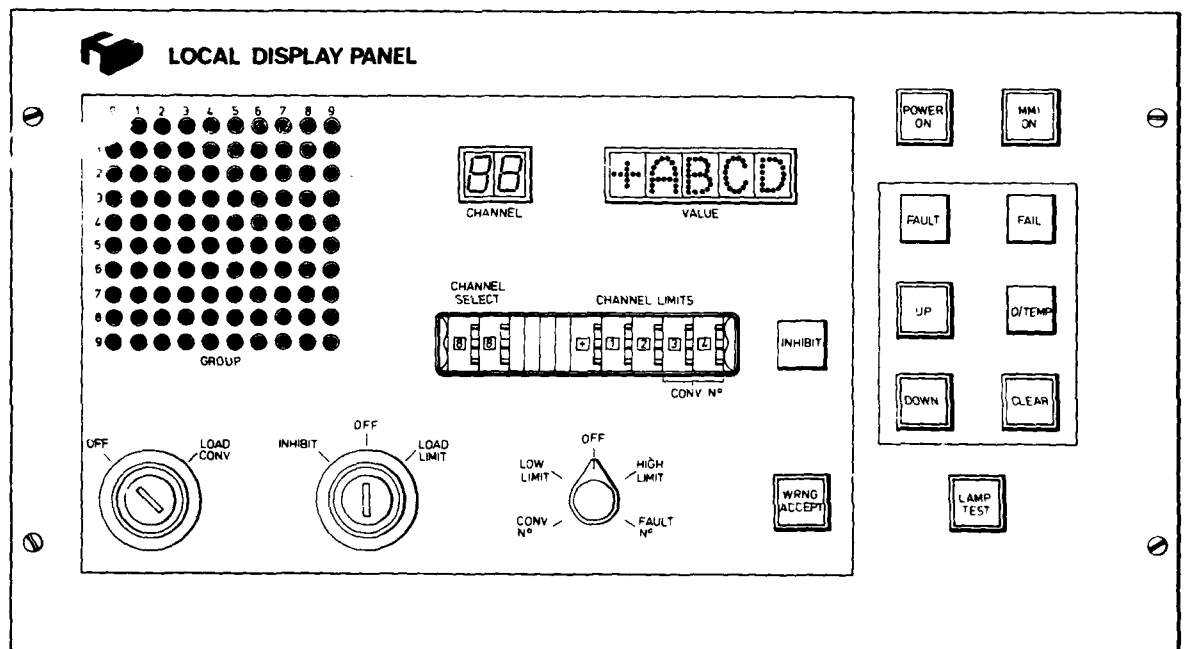- MAN/MACHINE INTERFACE
- CARD FRAME
- 3 cables 210 wires
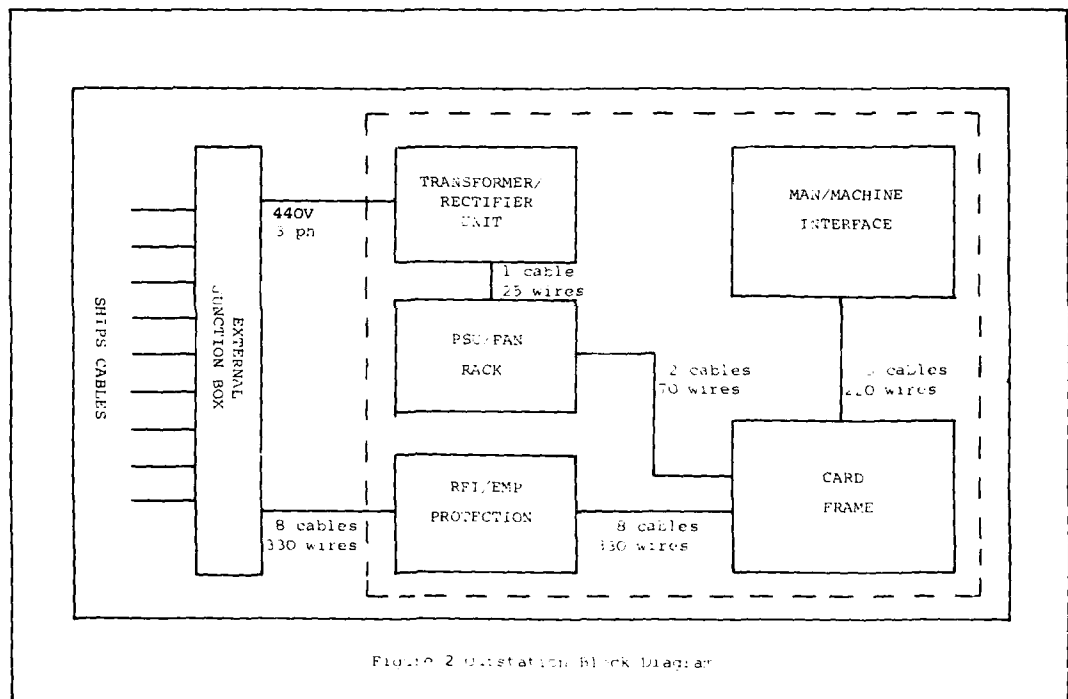
Figure 3. Local Display Panel

i) Indication of any channel going into warning.
ii) The ability to accept any channel in warning.
iii) The ability to view the current value of any channel.
iv) The ability to view the upper and lower warning limits of any channel.

In addition, the following facilities are available to the Maintainer. These maintainer facilities are operated via key switches, preventing unauthorised changes.

v) The ability to alter the scaling of any input channel.
vi) The ability to alter the upper and lower warning limits.
vii) The ability to inhibit any channel. This is to prevent unwanted warnings where a transducer is disconnected and/ or faulty.

The five units being modular, are capable of being independently tested. Using the card frame as the star point all the modules are plug connected using one to one cables.

Central Station   The hardware for the central station is, as far as possible, identical with that used for the outstations. The principle differences are the addition of the Group Warning Windows and VDU for the primary display and a unique MMI panel reflecting the functional task of the central station.

The Experience Gained

The most important outcome of the Evaluation system has been the reception it has been given by the Machinery Watchkeepers who have had the opportunity to see the system in operation. In spite of some shortfall in the performance of this system, all those concerned with the creation of the "Group Warning " concept are convinced that the philosophy is sound.

This evaluation system has demonstrated very clearly the penalties incurred by the requirement for nuclear hard electronics. In essence, to meet the specified radiation levels, the choice of semiconductor devices was limited to those fabricated using bipolar technologies. Since the number of transistors per chip is typically 7000 for bipolar compared with over 50,000 for MOS fabrication techniques, then it is readily apparent that the use of bipolar technology severely limits the amount of "intelligence" per chip available in the system. This situation is dramatically compounded when the range of support devices, such as USART'S etc. is considered. This results in poor system performance per unit cost when compared with MOS systems.

This limitation of component choice also has a major impact on the design and layout of the hardware with a very high component count per function necessitating sophisticated high current power supplies and distribution systems. Another effect of bipolar devices is that the very high edge currents demand the use of multilayer PCBs with corresponding cost and production timescale effects.

The evaluation system was configured for maximum flexibility with all I/O modules interfacing directly with the computer bus. (Fig.4) This arrangment permits all system changes to be made in software. With hindsight, this arrangement has resulted in maintainability problems, in spite of the extensive error reporting software and hardware status indicators. In practice, it has been found that the majority of system failures have been difficult to isolate and indentify, as they often involve a processor crash which renders diagnostic software useless, and therefore require skilled personnel and sophisticated test equipment.

The emphasis on generality and configurability in the software structure has resulted in cumbersome background tasks generated by the operating system overheads. When compounded with the heavy traffic conditions on the data links, and the comparativly low amount of processing power available in the bipolar CPU, the system response falls below the exacting requirements of this configuration, although very little software tuning has yet been carried out.

The Man Machine Interface design was successful in that once a prospective operator had been familiarised with the system, the operation of the system via the MMI was largely self evident. However, the panel is dedicated to its present task by the form of construction used, that is the use of separate switches/indicators etc., and its integrated nature with the system electronics in terms of signal drive These aspects also make the MMI a disproportionally large percentage of the overall outstation cost.

Using the experience gained on the Evaluation system, in conjunction with that gained on Intel 8085 based systems already at sea, a modified approach to the concept of the Group Warning system was adopted. Retaining all of the principle elements of the original system as envisaged by Vickers Ltd., excepting nuclear hardness, a modified structure for the hardware was evolved.

This modified system, referred to as Dynalec 6000, has been prototyped by HSDE to evaluate the system structure. This system differs principally in the following respects.

(a) Reduced nuclear hardness.

(b) The adoption of a partitioned structure, utilising a hardware driven input data scanner to acquire data from the input channels.

(c) The use of third generation VLSI computer chips and their support devices.

(d) Simplified software resulting from the synchronous, sequential operation of the outstation coupled with the use of dedicated intelligent devices to replace routine software activities.

Fig.5 shows how the outstation breaks down into three fundamental parts.

The first part is the array of input/output modules which form the plant interface. These modules provide all of the signal conditioning required for all of the commonly used types of transducers, eliminating the need for external signal conditioning.

B 2-8

D A T A   B U S
Evaluation System
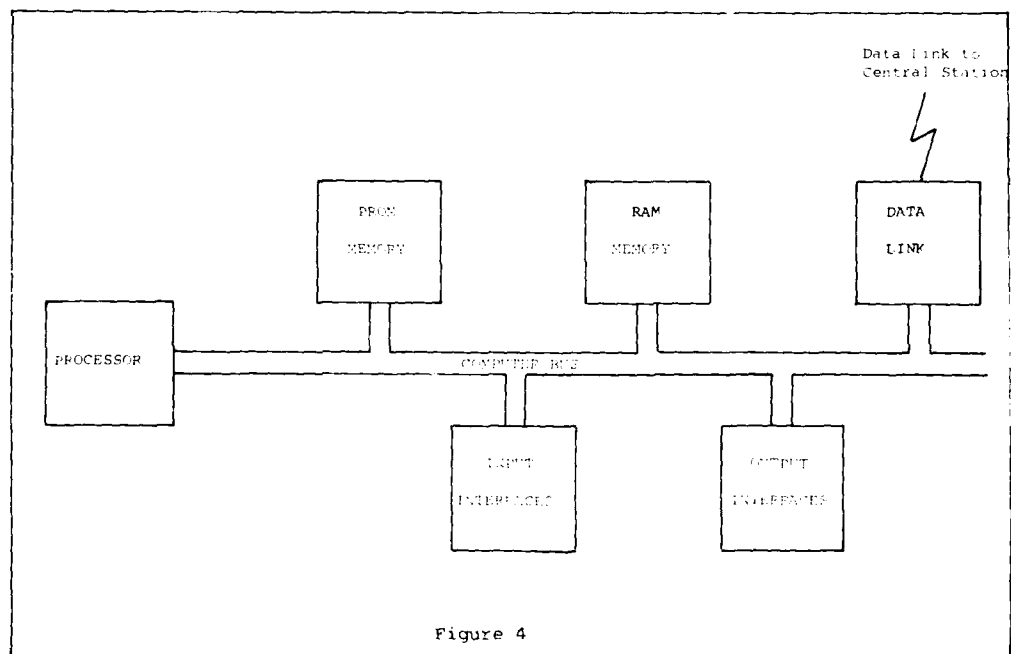
Figure 4

DATA BUS
Modified System

Data link to
Central Station

PROCESSOR
with inte-
gral memory
and serial
Data Link

SCAN
CONTROLLER

SIMPLE LOW SPEED BUS

INPUT
INTERFACES

OUTPUT
INTERFACES

COMPUTER
BUS
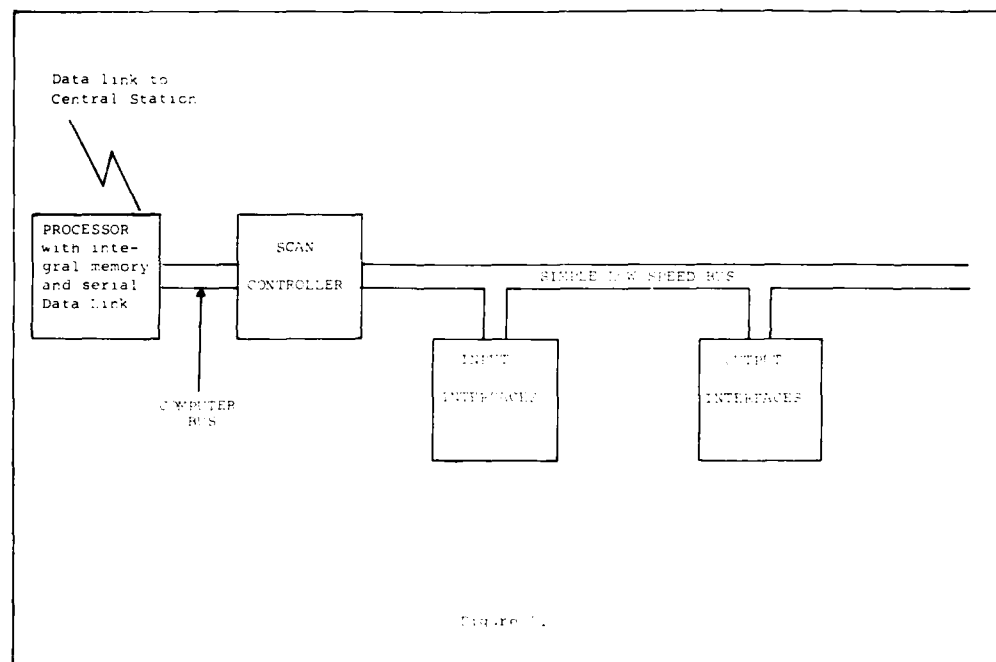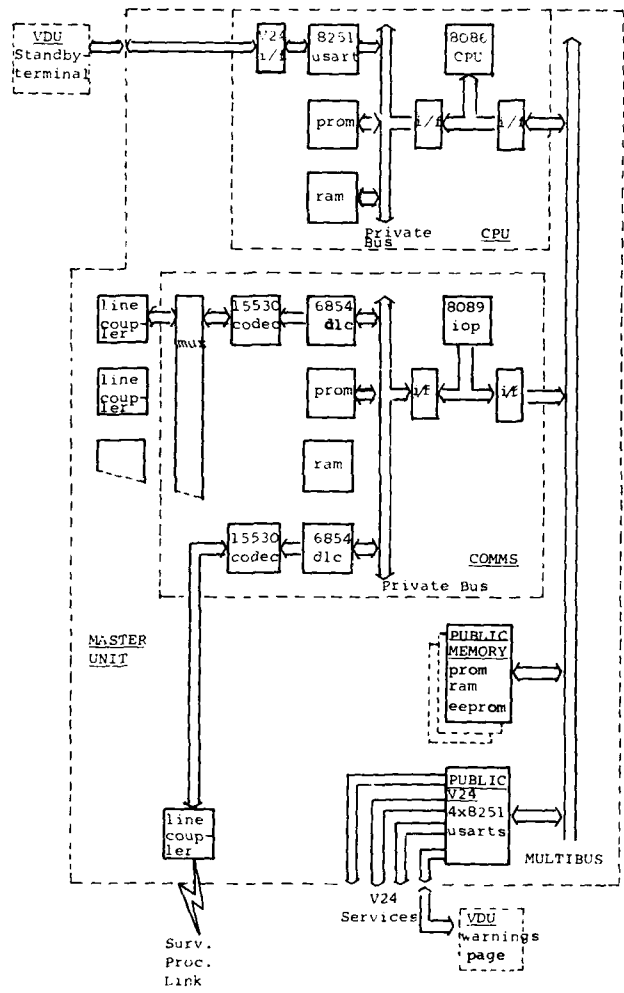
Figure 1.

Figure 6. D6000 Central Station

SCAN BUS
dig
ana

Private
Bus

RAM

PROM

6854
dlc

15530
codec

Line
coupler

8 Temp/Bal

RFI

AN I/P

8 Balanced

8251
usart

V24
i/f

i/f

RFI

AN I/P

8086
CPU

8089
IOP

RFI

LOGIC
I/O

i/f

COMPUTER

2 x 115
Vac
Supplies

PSU

SCAN
CTRLR
ADC
EEPROM
DPRAM

MULTIBUS

Test Access

MMI

Figure 7. Budget outstation

These input modules also give a measure of protection for the
system electronics against damaging transients and careless
maintainers. The system structure has been organised such that the
I/O modules carry the very minimum of the system electronics,
resulting in low cost, simple layout cards, providing the ability to
cater for new unforseen input/output requirements with very low appli-
cation charges. The circuit designs for the plant interfaces have
been closely modelled on those developed on the earlier evaluation
system.

The second part is the scan controller which controls the operat-
ion of the input/output modules. This module contains the high cost
parts of the data acquisition electronics such as the Analogue to
Digital Converter. The system used by this module to drive the
interfacing modules is based upon a simple counter and is configured
specifically for easy fault finding using test equipment limited to
the multi-meter level. The output of this module is a 15 bit data
word per channel held in a buffer store.

The final part of the outstation is the computer which, as a
result of the use of 3rd generation VLSI devices, can be organised as
a double module. This double module contains all of the electronics
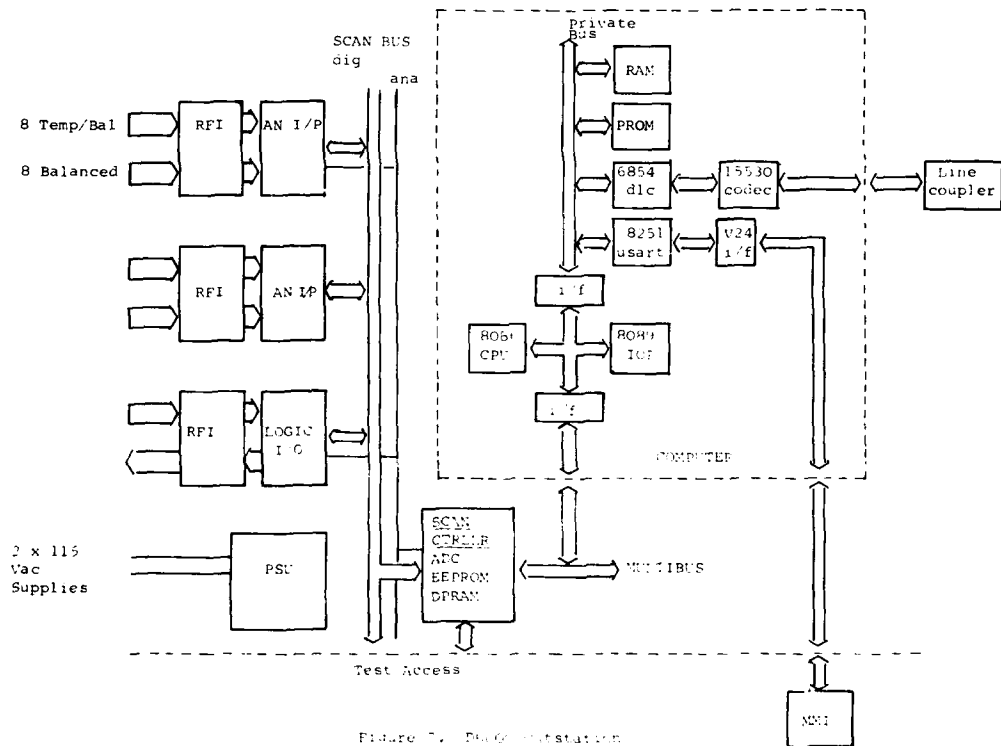which may prove difficult to fault find in service. Hence, in the
event of a failure, if the diagnostic software is unable to identify
the fault, then the technique of repair by replacement is invoked.
This double module performs the functions of scaling, comparison with
warning limits, warning flag generation, channel inhibit and data
transmission via the serial data link to the central station.

The strictly sequential operation, together with the intelligent
devices used to unload the processor of the communication burden,
reduce the software requirement for this system to approximately half
of that required for the previous bipolar based system. The programm-
ing language used is CORAL 66, the language preferred by the Ministry
of Defence.

One of the key features of the system is that the "intelligence"
is partitioned off into a single module, this allows considerable
scope to adopt alternative processors or use different programming
languages to meet individual customer requirements.

One feature of the system which is of major importance to a
system user is that the outstation is configured to the customers
signal requirements, on site, by ship's staff using the Man Machine
Interface, so eliminating expensive application changes.

The MMI in this system is connected to the outstation via the
industry standard V24/RS232 serial data link. This provides the maxi-
mum flexibility to match the customer requirements with the ability to
use almost any form of MMI ranging from simple commercial hand held
Micro terminals through conventional VDU/Keyboard terminals to spe-
cially designed intelligent panels tailored exactly to the customer
requirements.

With MMI design being such an emotive topic this "bolt on extra"
nature which permits even radical changes to be imposed on the design
with minimal impact on the system, is a valuable feature in reducing
system development costs and reduces the risk of ending up with an
unwanted compromise.   B 2-13

In order to cope efficiently with the high volumes of data, the central station utilises two double modules. One of these is dedicated to the communications task of receiving data from up to twenty outstations and supplying all of this data to a separate surveillance processor.

The second module provides all of the functional facilities such as the Group Warning Window drive, the warning VDU display, the Auto Inhibit facility, drive for logger/printer etc.

The industry standard common bus structure used by these two processor modules can be extended giving the ability to add on additional processing power to carry out Health and Trend monitoring tasks.

The use of third generation VLSI microprocessors and support devices has permitted a very much more efficient packaging arrangement to be adopted, such that now all of the electronics including the power supply and RFl filtering can be contained within a single 19 inch card frame. The component count is only 45% of that required with the bipolar system and the discrete wiring is reduced to less than 1% of the former level. The impact on both manufacturing costs and system reliability are self evident.

This compact nature now permits the overall electronics package of the outstation to be a Major Line Replaceable Unit. This enables all of the ships cabling to be installed to a special "junction box", and checked out with all transducers, prior to the electronics package being plugged into the "junction box". The electronics modules form Minor Line Replaceable Units.

Health, Trend and Performance Analysis

The by product of having all the plant data available at the central station is the ideal opportunity of introducing computer surveillance techniques. This may be carried out by either installing a separate processor connected by a serial data link, or by extending the processing capability at the central station.

The task of the surveillance processor is to present the extensive amount of information available in a variety of forms depending upon the purpose of the user. These techniques have been more widely used in industrial monitoring systems than in warships at the present time, and the examples below are taken from software developed by other product areas within the authors company.

    (a)   Storage of data at sampling intervals selected from an interactive VDU console, which may be milliseconds for performance analysis or 24 hours for logging or historical records.

    (b)   Averaging and correction of data. For a trend curve (Fig 8) readings are only taken after steady running has been established, and averaged to reduce scatter. They are then corrected for ambient and running conditions and a corrected value logged. These values can then be displayed on a time axis and extrapolated if required.

CORRECTED TURBINE ENTRY TEMP

Figure 8.

HEAT EXCHANGER EFFICIENCY

Figure 9.
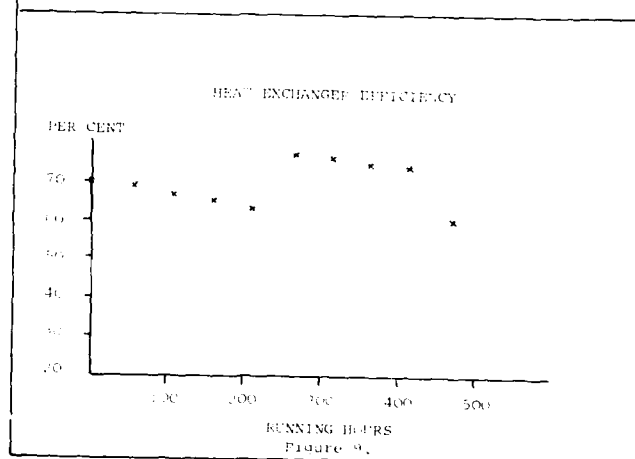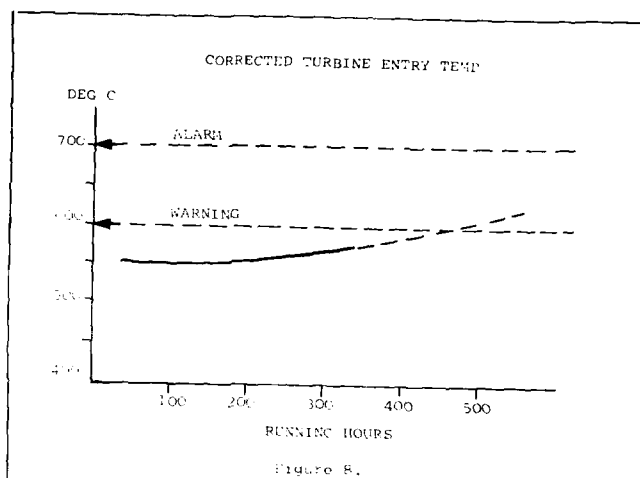
(c) Performance using non-dimensional parameters can be calculated and displayed both to help diagnosis and detect deterioration before damage results. The example of Fig 9 shows a sudden drop in efficiency which might easily be missed from examination of individual parameters.

(d) Presentation of data on the interactive visual display can be in graphic form or using mimic diagrams with current parameter values superimposed.

(e) The routine paperwork of logging and reporting can be reduced using keyboard entry to pre-formatted checklists, making more time available for using the health monitor techniques above. This increases the interest and technical content of the watchkeeper's role, which can otherwise be reduced to monotonous paperwork by automated control.

Summary

The evaluation system has clearly demonstrated the penalties incurred in implementing sophisticated systems whilst limiting the choice of semiconductor devices to the nuclear hard varieties. However, this system has proved the operational philosophy as well as providing invaluable experience on plant interfacing and software structure.

By taking advantage of the much higher "intelligence" level available in third generation V.L.S.I. processors, an alternative to the evaluation system is being developed by HSDE. The range of support devices available for third generation processors enable the overall system performance to be improved by several orders of magnitude whilst halving the component count. This saving is further reflected by a reduction in power supply requirements resulting in a more compact piece of hardware with improved maintainability.

Acknowledgements

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   Statement of Requirements for a Machinery Group Warning System Ref S/EL/SR109 Iss 04 January 1980.

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   Experience in Developing a Digital Distributed Control and Surveillance System.
   Ship Control Systems Symposium, Ottawa, October 1981.

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   Ref. TPL 1280 Iss 1 January 1981.

MACHINERY CONTROL AND SURVEILLANCE - SOFTWARE DESIGNED
FOR RELIABILITY AND MAINTAINABILITY

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and R. Foulkes, Y-ARD Limited, Glasgow

ABSTRACT

The paper is concerned with the design of software for multi-computer
systems to minimise the full life costs of those systems, with particular
reference to the design of software for two shipborne equipments:

(a) A machinery control system (Demonstrator) currently under
development for MOD by Hawker Siddeley Dynamics Engineering Ltd
(HSDE)

(b) A secondary surveillance system under development for MOD by
Y-ARD Limited of Glasgow, Scotland.

Particular attention is paid to the way the software is partitioned and
organised for multi-purpose use. The mechanism of test and verification
for common utilities is discussed and the mechanism for packaging the
releases of software is presented. The ability to move the software between
computers of entirely different architectures is stressed and the methods used
in the production of one of the utility packages are described.

With the benefit of hindsight, a review of the effect of the project plan
and of some of the lessons learnt during development is presented.

INTRODUCTION

As part of the ongoing work programme (Reference 1) to secure the
advances in new technology for future generations of control and surveillance
systems substantial progress has been made in overcoming many of the
problems likely to result from the use of computer software in those systems.
A first hand understanding of the difficulties likely to be experienced in using
distributed computers to perform a propulsion machinery control task was
obtained using a Propulsion Control System Test Rig (Reference 2). This
work showed that, in order to meet the requirements of reliable, maintainable,
transportable and flexible software, certain design objectives had to be met.
These were:

(a) A good software structure was required, whereby jobs to be carried out
within a processor were isolated from each other by an executive which
imposes constraints on the privileges of the individual tasks. This

SCCMMI

SYSTEM CONTROL UNIT

HARDWARE FOR PLANT &
H ▨ HIGHWAY I/O
I ▥ INTERFACING
DM ☐ DATA MANAGEMENT
MR ▦ MESSAGE ROUTING
CH ☐ COMMUNICATIONS HANDLING
C ▧ PROPULSION CONTROL

TRANSDUCER
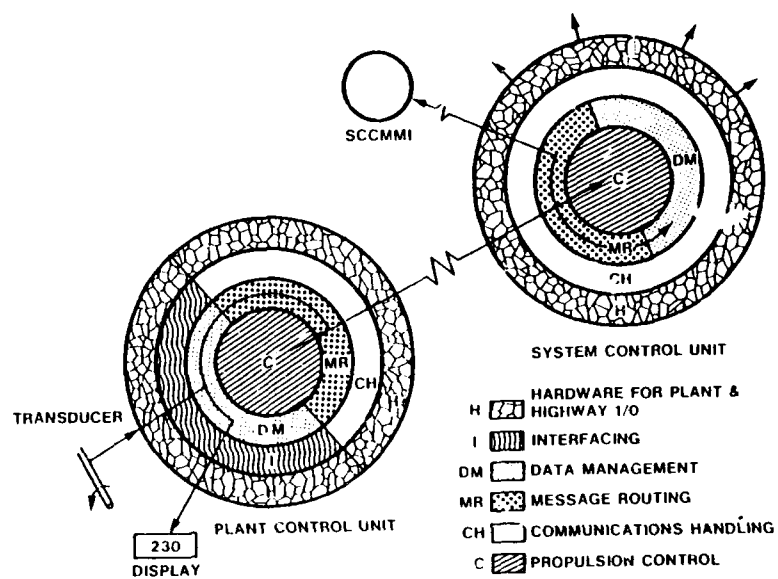
PLANT CONTROL UNIT

230
DISPLAY

Figure 1 - Software Structure

software structure was to be such that the data transmission system was transparent to the remainder of the software in each processor.

(b) The software design was to be modular for ease of documentation, testing and management. The documentation was to allow for a life of 25 years and remain as independent of the hardware as possible.

First the software structure will be described, then the main body of the paper will be devoted to describing the implementation of that structure to achieve the other design objectives and thereby meet the software requirements.

SOFTWARE STRUCTURE

A diagram of the software structure is shown in Figure 1. The main software tasks are shown, together with the hardware interfacing to the outside world. The executive which allocates the resources between the tasks is the MASCOT kernel which exists in each processor. Each of the software tasks shown is independent in the sense that it has a specific job to do and the only constraint on how the job is done is the way in which each function interfaces with another. Thus, a control sub-system may be designed or altered without having any detailed knowledge of, say, the Data Management Task but only a knowledge of how to interface with that task.

To explain the overall structure, consider a transducer signal from the plant which is required for a control function and which is to be displayed remotely in the Ship's Control Centre. The signal is first filtered, amplified, multiplexed and digitised by the hardware. It then passes to:

INTERFACING — where it is scaled and compared against limits. It then passes to:

DATA MANAGEMENT — where a system wide address is added so that information is clearly identified for use anywhere in the system. This task keeps a store of data and passes it out to consumers as required. The prime consumers are the Controls' (or applications') tasks located in each processor. To communicate between processors the Data Management in one processor initiates a data link to another processor on start-up. The Data Management task in the other processor constructs messages containing the required data which are then automatically exported each time the parameters are updated. Data Management uses:

B 3-3

Figure 2 - Typical Distributed Digital Control & Surveillance System

B 3-4

Legend:

Propulsion and Auxiliaries Secondary Surveillance

Main Machinery Control System (Demonstrator)

PCU   Plant Control Unit

DAU   Data Aquisition Unit

CSU   Central Surveillance Unit

SCU   System Control Unit

S^3 Ferranti Serial Signalling System Links

Ship Control Centre

Display Processor

Pass Display Console

Main Operator Console

CSU

Pass Main Processor

Communications Processor

DAU

Auxiliary Plant e.g. Chilled Water System

Main Electrical Supply System

SCU

SCU

To PCUs for Second Shaft Set i.e.
2 x GT PCU
1 x GB PCU
1 x CPP PCU

CPP PCU

Controllable Pitch Propeller

GT PCU

Gas Turbine

GT PCU

Gas Turbine

GB PCU

Gearbox

Input to Secondary Surveillance from the PCUs on the Second Shaft Set

MESSAGE ROUTEING   -   to steer messages to the correct
                                processor via:

COMMUNICATIONS HANDLING -   which organises the transmission.
                                This task contains the
                                implementation dependent aspects of
                                the communications' system,
                                sometimes called the high level
                                protocol. Messages pass from this
                                software task to the hardware
                                implementation of the data link used.

ERROR REPORTING   -   is a supervisory task which receives
                                notice of errors from all activities
                                in the software. These errors are
                                reported to the maintainer.

This structure has been implemented in a development contract placed
by MOD on HSDE for the Demonstrator control system which uses distributed
processors to perform propulsion control and surveillance tasks according to
their place in the controls' hierarchy Figure 2. The functional design
underlying the control system will be found in Reference 3.

Associated with the controls' system is a surveillance and data collection
system called the Propulsion and Auxiliary Secondary Surveillance (PASS)
system (Figure 2). This system development is described in Reference 4.
The software structure for the PASS system is similar to that used in the
Demonstrator control system using the same common tasks of Data
Management and Message Routeing, but with different applications software.

Software Lifetime and its Problems

Before starting work on a system containing embedded computers it is
worthwhile looking ahead to the maintenance and other operational problems
likely to be encountered during its lifetime, since that is where a large
proportion of its overall cost is likely to reside. In such a case as that which
we are considering, of fitting computer embedded systems to ship's machinery,
consider the following statements:

"It has been 20 years since the first ship was fitted with the NOPRANG
computerised machinery control system. Since then it has been fitted to
23 ships in the Fleet. Currently, only 2 (the latest built) of the ships are
running identical software. Using the 2 latest ships as a baseline, a recent
analysis of why the remaining 21 are running different software sets
revealed:

10 are different because the equipment they are controlling is different.

7 are different because they are using a variety of old computer hardware
still not replaced from the previous programme of refits of controllers
started 15 years ago.

13 are different because they are at five different operational
modification states and are awaiting upgrades.

B 3-5

The discrepancy in totals is caused by some ships having more than one reason for differences. We are looking forward to a period of stability after the current refit programme has replaced all the computer hardware with the MIGHTYMOUSE chip".

It may be that there are no circumstances in which the reader, as, say, the person responsible for the control system, would have allowed it to get into such a state. Unfortunately, many engineers have discovered that it is impractical to keep the design state of computer embedded systems, such as ships' control, synchronised with each other, often owing to circumstances beyond their control. It is, therefore, worthwhile acknowledging the above scene as a remote possibility, ensuring that it could be coped with, and then trying to avoid getting into it! The big problem is what to do during development to enable the maintainers of the system to cope. This section of the paper describes some of the areas considered during development of the new generation of UK surface ship machinery control and surveillance system, what was done about them and, with the benefit of hindsight, what has been learnt.

Configuration Control

Often left until last, the area of software and hardware configuration control should be tackled early in ..ne development phase. By 'configuration control' we mean the ability to guarantee an accurate knowledge of exactly what is fitted to operational or experimental systems to allow the diagnosis of faults and achieve control over the development of (or other changes to) the system.

In which ways do the requirements of configuration control affect the design? The following provides some indications:

To control the hardware and/or software as one massive block with no internal structure is very difficult. Fault reports from one issue of the system (such as a ship) are difficult, if not impossible, to relate to other issues. Slight differences between hardware fits are very difficult to manage. Configuration control demands a software and hardware hier-archical structure of assemblies, sub-assemblies and components in order to manage both software and hardware. It is almost impossible to generate retroactively such a hierarchical structure in an implementation designed and built without it.

Configuration control makes demands on the way in which changes are implemented to both hardware and software and the way in which issues to the field are synchronised with the changes. The designer has to try to reduce the scope of changes to both hardware and software caused by outside influences. It may appear obvious that changes relating to the operational parameters of a gas turbine should be located in one small area of software and hardware and not scattered all over the implementation; not so obvious, perhaps, is the necessity to do the same for communication hardware changes, the software for which occurs in every computer.

B 3-6

The following gives some idea of the impact of configuration control on the implementation, that is, the work necessary to produce one set of the hardware and software and get it working in a ship:

It is quite difficult to change implementation engineers from working in an environment in which there are few checks on the ability to change permanently a module of software (or, for that matter, a printed circuit board) to the environment demanded by configuration control. It is important, therefore, to start out with a moderately disciplined approach and to relax procedures where necessary, rather than to start out in an undisciplined way.

Configuration control demands that the system for a particular ship can be constructed from the documentation alone, any knowledge inbuilt into the heads of the developers being a dangerous thing. In order to validate such a requirement, the original system must be constructed in a way that allows someone not associated with the implementation team to generate a system for a ship.   Before development is complete the configuration control department must issue a ship fit system.

How does the way in which the software has been designed for the described systems assist in the area of configuration control? Every item of software maintained in magnetic form, whether computer programs or build instructions, is part of a 'module' which corresponds with a circuit diagram in hardware terms. The module contains some administrative information such as name, modification states, title, description, Q-A approvers, etc., together with the appropriate code. At the time of writing only the shared code areas are under full configuration control. The size of each module is controlled in a similar manner to the contents of a circuit diagram, i. e. on the basis of a reasonable looking area of code, functionally separate from other areas and assessed by the quality control group as being a reasonable module size and complexity for support purposes.

The modules are the components of 'packages' which generally implement areas of functionality such as communications, data management, machinery control, etc. A package is the smallest issuable entity and may contain pointers to other packages to completely define a software issue. The user fault reporting system is based on packages, only being routed down to module level by the subsequent analysis of the fault.

Although the tight change control demanded of the final configuration control cannot conveniently be applied during development, the general framework of development within such an environment has been maintained. Typically the configuration control system retains all the module sources, retaining old versions appropriately, and producing suitable reports for the Q-A inspection which is generally only carried out via configuration control. During development the requirement to raise a change notification for every single code change is relaxed, We have found, however, that subsequently adding an 'authority to proceed' to a change request system is easy compared with retroactively adding a complete configuration control system. It has been found that, after initial reluctance, the programe designers and implementers accept the use of configuration control as an improvement of

facilities and not an imposition of management.

Testing and Re-testing

The requirements of testing and re-testing are important factors in the design of long life software. It is necessary to build the ability to test the software into the design. If, for example, a large quantity of software is intimately linked to the hardware on which it runs, making it impossible to test the software remote from the target hardware, it is likely that a considerable portion of the Fleet will be tied-up alongside for software testing purposes. Over the lifetime of the software, changes are often made in every functional area. Since, unhappily, one of the known characteristics of fixing software problems is the generation of new ones, it is important to at least be able to re-execute the tests which were originally used to declare the software 'working', and preferably to be able to extend the tests or test cases to include the fault which previously escaped.

In a similar manner to electronic hardware, the question of how automatic the testing process should be, arises. A fully automatic test system for which a machine displays 'PASS' or 'FAIL' is obviously preferred, but is a higher capital outlay. Furthermore, some areas are not as amenable to this form of testing as others. However, the sensitive areas of both the systems described are covered by pass/fail tests which are configurable in several different ways. The main areas covered are:

Data accessing routines
Communications
Data management
MASCOT executive

All the test software, including any test case files, are held under configuration control, along with the software they are testing, and are maintained to the same strict standards of quality. The tests have been designed so that they can be executed by other than the original software designers and implementors. Generally the test programs provide an environment which looks identical to the real world from the point of view of the program under test. In some cases, particularly when time criticality is of great import, this is difficult to do, and in some cases makes certain demands on the final hardware such as loop-back connections in communication systems.

Documentation and Quality Control

The often stated demand that long lifetime software should be 'well documented' has the difficulty that the words 'well documented' are not well understood. The requirement is to allow for many changes of staff members during the project lifetime. In a similar manner to modularity, clear documentation is almost impossible to fit retroactively to developed software. Not only is it difficult to do but it is also psychologically bad, in the sense that it is usually seen as a chore to be completed after all the interesting programming work has been done. Often the engineers producing the software escape to other jobs before completing the documentation.

In what ways do the systems described meet the documentation requirements of long lifetime software? An attempt was made to document all the software from the outset to a standard defined by JSP 188 (Reference 5) which requires a hierarchical breakdown based on functionally identified areas of software. The documentation was made a part of the quality and progress inspection procedures during the development, being used for areas such as design walkthroughs and the contract progress approval procedures.

All, of course, was not sweetness and light. Most of the problems were caused by tight tirr escales squeezing out action required by quality checks on the documentation during the later stages of the project. The documentation strayed from the ideal, but never approached the situation of being irrecoverable.

Multi-Purpose Use

Some areas of software are well suited for sharing amongst similar projects. There are considerable benefits if sharing can be achieved viz:

    More reliable software (checked out by more users)
    Lower support costs
    Lower development costs
    Cross-product fertilisation of techniques and ideas

Early in the development cycle some areas which were suitable for sharing between similar projects were identified viz:

    Data accessing routines
    Data management
    Some aspects of communication
    MASCOT executive

even though they had to run on totally different computer architectures.

It was not fortuitous that these areas were shareable. Considerable effort was put into functional identification during the design stage. The demands of shareability across different projects and computers are quite stringent with regard to the methods of packaging and documenting. With deliberate intent it is possible to identify such areas and the projects described demonstrate this by sharing several areas between them and with other projects.

A word of caution here: Sharing has to be judisciously done, since there is often a trade-off between commonality and efficiency. In general, the closer the programming is to the application, the more difficult it is to share with other applications. If one project demands some modification to a package which is not acceptable to a sharing application it is necessary to support both applications separately. Packages which are 'almost' the same are very difficult to control as a single entity.

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Software Mobility

One of the demands of both long lifetime software and sharing of programs
between projects is the ability to run the programs on more than one
computer. There is significantly more to the problem than choosing a high
level language and programming everything in it. The decisions begin at the
design level in choosing the levels of abstraction to ensure that the
peculiarities of one computer are not built into the software at too high a
level. Inevitably there are differences between languages, executives and
interfaces, but with careful partitioning   of the software it is possible
to minimise the effort needed to move the software. In the projects
described the techniques used to assist in ensuring the software is mobile were:

.   Use of MASCOT (Reference 6) as the executive interface

.   Programming in Official Definition (Reference 7) CORAL 66 and
     adjustment with a pre-pass program to particularise for a computer

.   Development on several different computers (PDP 11,   INTEL 8080,
     Ferranti F100L) and movement several times during development

.   Use of Test harnesses to allow re-testing on different computers.

There are some problems to which we currently have no solution and with
which we have to live; amongst these are:

.   Differing representation of data items, such as floating point, causes some
     problems, particularly if the number of words is different

.   Differing instructions necessary to construct the software, particularly
     where instructions down to placing the code in read-only memory are
     required

.   Differing usage of resources, such as stack allocations, invalidating the
     test cases designed to highlight resource problems.

Example of multi computer, multi-use package

The following is an example of a package which is currently used in three
systems which was designed both for multi-computer use and to allow
transportability between computer architectures.

The particular package described is DATA MANAGEMENT, a package
devised by Y-ARD under contract to MOD for an area of software which
was unsuccessful during a previous research phase, produced and tested
by HSDE and transferred under configuration control to be used on PDP11
computers for PASS and on F100L for the Demonstrator. It would be an
indictment of the documentation scheme is this paper had to create a special
description of data management or its test system; modules from the package
will therefore be used.

```
MODULE NAME
  DMTASK
DESCRIPTION CLASSIFICATION
  UNCLASSIFIED
CODE CLASSIFICATION
  UNCLASSIFIED
TITLE
  DATA MANAGEMENT TASK DESCRIPTION
TYPE                    NAME
  DESCRIPTIVE           DMTASK
DESCRIPTION
      This module describes Data Management at the task level. It is a
  generalised description that may be adapted as a basis for particular
  applications.

  1. AIMS OF DATA MANAGEMENT.
      Data Management is a method of transmitting data throughout a distributed
  computer system. The types of data item (parameter) handled have the following
  characteristics.
        a A unique identifier can be given to the parameter. DM requires a
          Parameter number.

        b The parameter has a fixed length. DM allows any number of parameter lengths.
                                      But requires that the first word of a
                                      parameter is the status word.

        c The parameter has only one source. DM requires this.


      Message data that may have varying length and meaning and may have multiple
  sources and that ceases to be meaningful once operated upon is specifically
  excluded. The characteristics of data management are:
  (a)the originator need not have knowledge of the users of a given
      parameter.
  (b)the users need not have knowledge of the originator of a given
      parameter.
  (c)the originator and users may be in different computers.
  (d)use of facilities of data management does not require a detailed
      knowledge of the format of the data management data base.
  (e)the method of communication of parameters throughout the system
      is hidden from the user.
      Data Management undertakes the task of communicating parameter data throughout
  a system such that up to date values of parameters are available to all users that
  require them as soon as possible.
      DM requires that user activities declare their interest in particular
  parameters. If the user activity requires the parameter for read then DM sets
  up the linkages to the parameter source, if the source is in a remote
  computer then the linkages are set up to have the remote computer send the data value
  to the local computer each time the value is changed. If the user activity
  generates a parameter then DM informs the system so that local and external links can be made
  with activities that require the parameter value.

  2. DESCRIPTION OF THE TASK
      The DM Task consists of a number of subsystems of which there may be
  one or more in each computer that requires DM facilities. The actual number
  is dependent upon the application. The structure of the subsystems is
  described in module DAMASS.
      The subsystem communicates with

        a Other DM subsystems - External links

        b USER TASKS via a POOL - Local links.

  The form of the external links is system dependent.
  The POOL is defined by DBDES. Access to the local
  PARAMETER POOL both by DAMASS and USERTASKS is only made by via operators. These
  operators are described in module DMOP.

  3. INITIALISATION OF SUBSYSTEM AND DATA AREAS
      It is necessary to initialise the subsystem and the data areas. The
  method of doing this is described in module DMINIT.
ENDOFDESCRIPTION
ERRORS REPORTED
```

Figure 3 - Introduction to the Concept of Data Management

```
'COMMENT'

   MODULE NAME
      DM2SUBSYSTEMDES
   DESCRIPTION CLASSIFICATION
      UNCLASSIFIED
   CODE CLASSIFICATION
      UNCLASSIFIED
   TITLE
      DATA MANAGEMENT SUBSYSTEM DESCRIPTION
   TYPE                         NAME
      DESCRIPTIVE               DMSUBSTEMDES
   DESCRIPTION
      This module describes a DATA MANAGEMENT Subsystem.
      The subsystem is illustrated in figure 1.
```
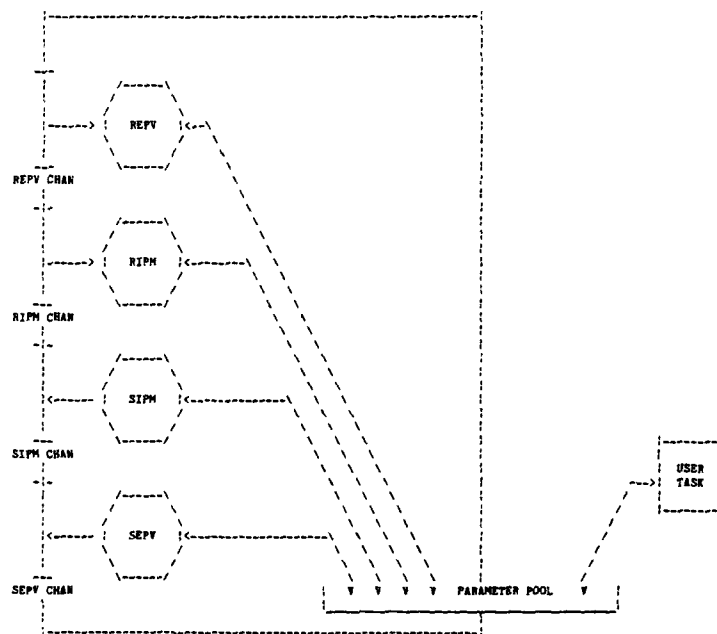

FIGURE 1 - DATA MANAGEMENT SUBSYSTEM

Figure 4 - Sheet 1 Parallel Co-operating Processes in Data Management

DESCRIPTION OF SUBSYSTEM

PARAMETER POOL
This pool contains tables of information about which locally written
parameters are required by other DM subsystems and which DM subsystems
require them. It contains information on parameters whose source is
non-local but are required locally. The complex data structure also contains
pointers into a list of the read, write and edge-trigger tables set up
by the user tasks.

USER TASK
This represents the user tasks which access the DM PARAMETER POOL using
the access procedures defined in module DMOP.

CHANNELS
The channels REPVCHAN,SEPVCHAN,RIPMCHAN and SIPMCHAN are used to send/receive
messages for the corresponding activities (see below). The channel protocol
is defined in module SIMPLESTRUCTURE.

REPV
This activity receives messages containing parameter update values from
remote DM subsystems. The values are written into PARAMETER POOL where
they can be read by USER TASK. If any of the parameters are edge-trigger
accessed then the appropriate STIM is made on the USER TASK. The activity
root procedurre is defined in module REPV.

RIPM
This activity receives messages from remote DM subsystems. These messages
are, in general, used to set the links between the DM subsystems and
involve declarations of parameters availability, requests for access to
parameters not available locally to the requesting subsystem, access
cancellations etc. The message protocol and message content is defined in
defined in module IPMDES. The activity root procedure is defined in module
RIPM.

SIPM
This activity is used to send messages to remote DM subsystems. The
messages will be received by a RIPM activity in the remote processor see
RIPM above. The activity root procedure is defined in module SIPM.

SEPV
This activity sends messages to remote DM subsystems containing parameter
update values of locally written parameters. It is activated via the edge-
trigger tables in PARAMETER POOL when externally requested parameters are
updated. The activity root procedure is defined in module SEPV.

Figure 4 - Sheet 2 Parallel Co-operating Processes in Data Management

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MODULE NAME
  DM2TEST
DESCRIPTION CLASSIFICATION
  UNCLASSIFIED
CODE CLASSIFICATION
  UNCLASSIFIED
TITLE
  TEST SYSTEM FOR DATA MANAGEMENT
TYPE   NAME
  DESCRIPTIVE   DM2TEST
DESCRIPTION
  This module describes a test system for Data Management Task.

  The D.M. task operates as a set of functionally identical subsystems,
  possibly in separate processors and the test system takes the following
  into consideration.
  a) To test the interaction of D.M. subsystems fully at least two D.M.
     subsystems must be included. They may or may not be in the same
     processor.
  b) Even when in separate processors the D.M. subsystems, from their point
     of view, will appear to communicate with each other directly through
     MASCOT channels. This is achieved by using a suitable inter-processor
     communications facility.
  c) Ideally the test should be independent of the number of D.M. subsystems
     (configurable during initialisation at all levels) and whether they are
     in separate processors; However due to size restrictions it will have
     a fixed configuration of two D.M. subsystems.

  For the test a D.M. subsystem will be attached to one of two harness types

  a) Master Harness. There will be one Master Harness in a test system.
     (See MASTER).
  b) Slave Harness. There will be a Slave Harness for the secondary D.M.
     subsystem. (See SLAVE).

  The test functions to be carried out are described in TEST FUNCTIONS and
  the following test strategy is adopted.
  a) each D.M. subsystem, SLAVE or MASTER is referenced
     by a D.M. Subsystem Identification number for the test. (See INITDEF).
  b) associated with the slave D.M. is a set of parameter numbers X00-X99
     where X is the D.M. Subsystem Identification number of the slave.
  c) parameter X00 is taken to be the synchronisation count and its value is
     adjusted by the master to indicate the stages of the test to the slave
     subsystem and the parameters to which it should have write access.
  d) the slave harness is as simple as possible and takes edge-trigger
     access on parameters X00-X49 and write access for the parameters
     X50-X99. When any of the ET parameters are written to the slave writes
     the new value of XYZ to XYZ+50.
  e) the master is in complete control and executes the test reads, writes
     and ET access on the parameters, both local and external. The master
     will have full knowledge of the external parameter states and
     values because of c) and d) above.

  The steps in the testing of the Data Management Task are as follows
  a) test the master and the single slave, within a single processor.
  b) test the master and the slave in separate processors.
  c) test the master and several slaves, all in separate processors. This
     will require modification to coding in DM2TEST.

Figure 5 - Test Techniques used in Data Management

MODULE NAME
  DMTESTSYSTEM
DESCRIPTION CLASSIFICATION
  UNCLASSIFIED
CODE CLASSIFICATION
  UNCLASSIFIED
TITLE
  MULTI-PROCESSOR DATA MANAGEMENT TEST SYSTEM
TYPE   NAME
  DESCRIPTIVE   DMTESTSYSTEM
DESCRIPTION
  This module describes the principles behind the design of a multi-
processor Data Management test system.

  The test system is designed with the following in mind
  a) Wherever possible the test software should be configurable and easily
      adapted to any number of processors.
  b) In the normal operation of the test _'l operator interaction should
      be confined to a single processor to make the execution and checking
      of the test operation as simple as possible.
  c) The test is intended to exercise the inter-subsystem protocols of
      Data Management in a target hardware multi-processor environment. It is
      not intended as a comprehensive test on the user interface or a line-by-
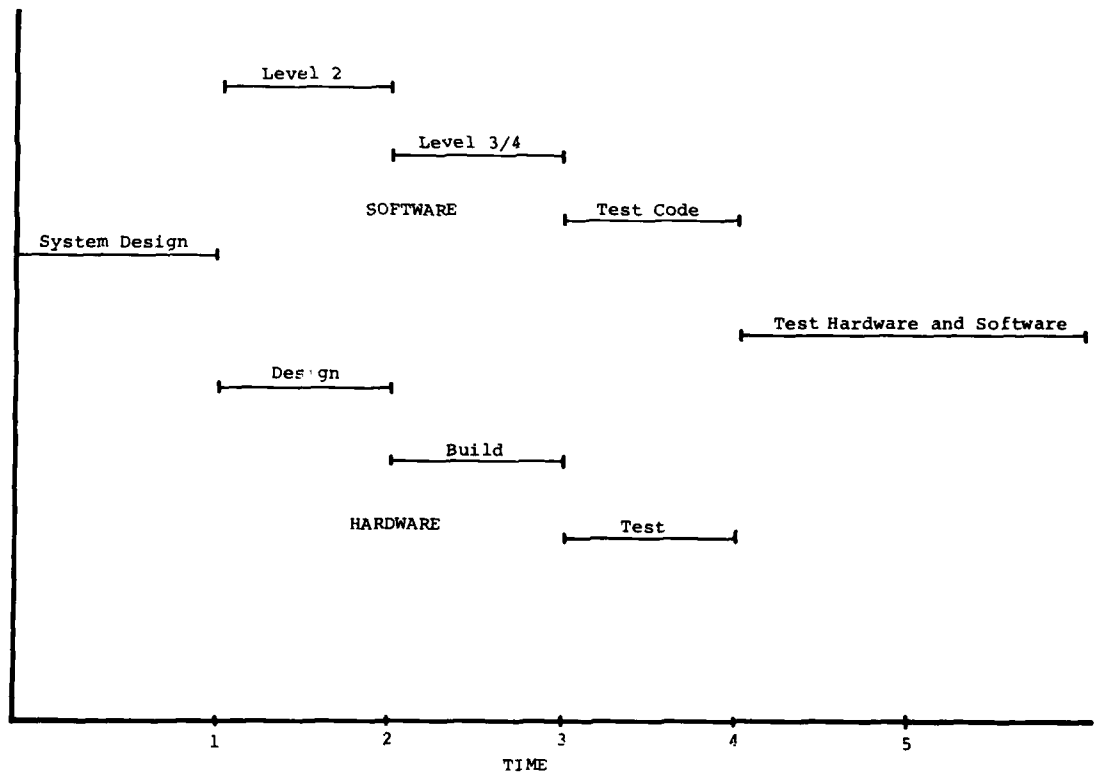   line test of the internal logic.

  The following test strategy is adopted.
  a) There is one "test master" processor containing the "test master"
      subsystem and each of the other processors contain a "test slave"
      subsystem. The "test master" invokes all operator interaction.
  b) It doesn't matter which of the processors contains the "test master"
      subsystem but the communications in each processor should be configured
      as if for the final system.
  c) The "test master" subsystem takes write access on two parameters
      1) 1 - this is a control parameter and the slaves take special
             action dependant on its value, in this way the master will
             know what should be happening in each of the slaves at any
             given time.
         100 - this is a "seed" parameter and other sets of parameters,
             whose sources are in the slaves, have their values updated
             to match the "seed" parameter.
  d) The "test slave" subsystems take write access on their own primary
      parameter and keep it updated to match parameter 100 i.e. slave number
      1 copies value of 100 to 101, slave number 2 copies value of 100 to
      102 etc. The slaves also read all the primary slave parameters and
      write the updates to a new parameter i.e. 10X - 11X where X is slave
      identifier and Y is the slaves own identifier. When there are three
      slaves then slave 2 operates with 100-102,101-121,102-122 and
      103-123. This means that every test subsystem reads a parameter from
      every other subsystem and every subsystem writes a parameter which
      is read by every other subsystem.
  e) The "test master" takes read access on parameters 111 ... 11N
      where N is the number of slaves. Each update to 100 should cause
      the update to eventually be made to all of these parameters.
  f) The test is made continuous by the master using the control word to
      tell the slaves to cancel write access on its parameters. The master
      then waits until all its read parameters have a status showing that
      the parameters have no current source i.e. all cancels sequences are
      complete, it then sets the control value to tell the slaves to
      re-request write-access to its parameters. After a sequence of value
      updates a cancel word is sent and the cycle is repeated.
  g) The subsystems are made configurable with respect to parameter size
      and the test should be repeated for all sizes or if memory space allows
      then multiple copies of the subsystems should be run concurrently
      for more than one parameter size.

  The "test master" subsystem is described in module MPDMMASTER
  The "test slave" subsystem is described in module MPDMSLAVE

Figure 6 - Multi-Processor Testing of Data Management

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Figure 7 - Plan 1 Conventional Development Tied to New Military Hardware
B 3-16

Level 2

Level 3/4

SOFTWARE   Test Code

System Design

Test Hardware and Software

Design

Build

HARDWARE   Test

TIME

1   2   3   4   5

The data management package for one type of computer architecture (such as F100L) comprises approximately 90 separate modules of documentation, application programs and test programs, running to 250 sides of paper and so the following is a rather brief extract to illustrate the salient points. Figure 3 is a module called DMTASK which introduces the concept of data management. Figure 4 is the first few lines of the module DMSUBSYSTEMDES, which describes the breakdown of data management in terms of parallel co-operating processes. Figures 5 and 6 are the first few lines of modules DM2TEST and DMTESTSYSTEM which give some indication of the test methods used to test and verify itself plus verifying the underlying facilities such as communications.

Considering that there was no experimental model of data management, we feel that the design of DATA MANAGEMENT is in a reasonable condition after completion of integration . There are a few philosophical problems associated with related attributes of parameters such as titles which would need resolving if DATA MANAGEMENT were to be applied to systems larger and more complicated than those described.

INFLUENCE OF THE PROJECT PLAN IN ACHIEVING LONG LIFE SOFTWARE

Unlike commercial computer systems, military systems usually require special hardware to meet the severe environment. Unfortunately, this hardware is not always readily available in the packaging required. If a project is fortunate, then a computer of the correct size and speed will be available with all the necessary interface cards and development facilities. Even so, as a target system it will be expensive, have a long lead time and be limited in its suitability for developing software. If the hardware is not fully developed then this must be added to the overall development plan. The manner in which this work is included into the development plan can make a great deal of difference to the confidence of achieving the software targets set earlier in the paper. A common error, for example, would seem to be the close dependency of the hardware and software parts of the programme. To illustrate the problem, consider two plans for the development of a prototype multi-computer system.

Plan 1 - Conventional

Figure 7 shows a conventional plan ostensibly designed for minimum timescale and material cost. The problem is that hardware is never available early enough to allow the software testing to be given the time it needs. Often the plan will show a very short integration phase but experience has shown that this will take the same time as the software development. Clearly the software programme cannot phase-in communications testing as early as required because all the hardware is needed before a start can be made. As hardware is usually made available serially so the integration can only start at the end of the hardware programme. If the hardware programme slips there is no recovery possible and the software testing will have to wait.
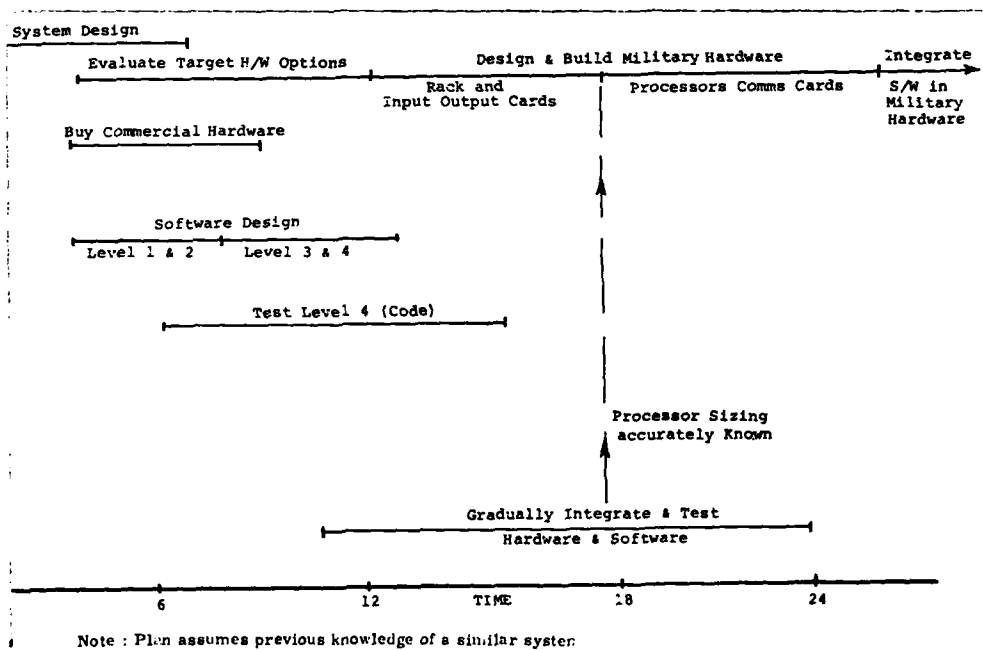
Figure 8 - Plan 2 Decoupled
Using Off-The-Shelf
Hardware With Parallel
Military Hardware
Development

System Design

Evaluate Target H/W Options   Design & Build Military Hardware   Integrate

Rack and   Processors Comms Cards   S/W in
Input Output Cards   Military
                                                           Hardware

Buy Commercial Hardware

Software Design

Level 1 & 2   Level 3 & 4

Test Level 4 (Code)

Processor Sizing
accurately Known

Gradually Integrate & Test
Hardware & Software

6   12   TIME   18   24

Note : Plan assumes previous knowledge of a similar system

Plan 2 - Decoupled

A major improvement would be to decouple the hardware development programme and create a separate software test environment. The plan is shown in Figure 8. Here, commercial hardware is procured which will allow testing of the high risk software areas, namely the communications and data mangement tasks. The applications software can also be tested in a data management environment in a large processor, and timing information obtained. The advantages of this decoupled approach are:

(a) The software programme can be adjusted so that the communications software is produced first, thus giving ample time for the testing.

(b) There is minimal risk to that programme from outside (hardware).

(c) The test environment can remain available for modification proving or any parallel work.

It may be felt that the cost will be higher because of the extra hardware required for software testing. This may be true but the risk has been substantially reduced, not only to the software programme, but to the hardware programme as well.

The hardware part of the plan shows an early evaluation phase to gain familiarity with the machine (or machines) to see if the development tools are adequate, and to carry out bench mark tests. Once the software design has reached the point where system parameters, memory, speed and communications can be established, then the correct machine can be chosen. Many projects choose the machine beforehand and find great problems when they have to shoehorn the software in later on. The later the decision on the processor, the lower will be the risk. The result of this revised plan could be a slightly longer and more expensive programme, but the plan is much more realistic and the confidence of achieving a working system much higher. The resulting system will be to a much higher standard. It will not be necessary to find a new processor during development because the original one was unsuitable, and it is likely that the software goals for quality will have been achieved.

This decoupled plan has been used for the development of the PASS, system, Reference 4, with, in this case, development of the target hardware not starting until after production and evaluation of a prototype system using commercial hardware.

Lessons Learnt

Many of the lessons learnt during the development of machinery controls systems will have been learnt by anyone embarking on the development of a distributed system for the first time. The major problem was the under-estimation of the risk and the unsuitability of the plan. More material (Reference 8) is now available which shows the standards which must be set in terms of project milestones and software quality assurance, but the difficulty contractors have is in obtaining realistic estimates and assessing the risk

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involved. With new technology the planner needs experience to achieve a minimum risk solution. Contractors must heed the lessons of the past and not propose development programmes which try to minimise the declared time and cost but contain an inherent undeclared risk

The main lesson learnt during the Demonstrator development from a project plan viewpoint was that the hardware development plan was too ambitious (e. g. nuclear hardening) and too closely tied to the software test programme, i. e. the conventional plan was used. Also the input/output cards were closely tied to the processor bus. A separate processor-independent bus would not only reduce the technical problems but enable different processors to be used with the same input/output cards. For the Demonstrator system the software structure and design was at an embryonic stage when the main development contract was started. Due to the tight timescales imposed, the necessary time required to resolve fully interface and structural design aspects was not available. Thus some work is still required to achieve fully the standards set, but additional work done on the Data Management and Message Routeing packages has enabled them to be made available commercially. A production standard has therefore been achieved in some areas. With hindsight an intermediate development stage would have been advisable. This, coupled with a separate software test environment using more powerful processors, would have helped to gain confidence in the software design at an earlier stage. Too early were we constrained by target hardware and software limitations, like memory size and link editor table sizes. More time was also needed to familiarise software producers with the philosophy and intricacies of the design. The consequence has been that premature decisions have been perpetuated, with the result that modifications will be required in some areas in due course.

Inexperience of software of this capability also led to some misunderstandings of the software test philosophy required for long life software. It became apparent, too late, that the problems associated with the test and integration strategy were not fully understood by the implementors. The main problem was that, for test purposes, a 'module' was defined at too low a level. When modules were combined, problems in the overall design became clear and also optimisation was required. The iterative loop to correct these design problems meant that re-testing at the low module level became tedious and, by its sheer volume, fell into disuse. This experience confirmed that the level of testing is one of the most difficult decisions taken during a project. With the right level of module for testing and then automating as much as possible, re-testing after modification is encouraged and labour costs are reduced. To achieve this requires a well thought out software development plan and some previous experience. Again, an intermediate stage would have helped.

CONCLUSION

The software design for future systems has been thought out with a view to minimising support and increasing reliability. The recommended approach is to use a modular design which eases configuration control and to automate as much as possible. This approach allows advantage to be taken of future advances in technology and will enable more fully integrated ship's systems to be produced in the future.

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The traditional approach to system development which includes hardware and software design and manufacture in parallel, and culminating in a long period of integration (typically 50% of the overall timescale), needs to be re-assessed   To give confidence to the system specifiers that digital technology is not a high risk solution, the problem areas need to be identified and resolved as early in the programme as possible. It is suggested that decoupling the hardware and software programmes, whilst possibly increasing the apparent timescale of the overall programme, would reduce the risk of over-run and cost escalation.

The development work so far shows that there has been substantial progress achieved in meeting the design objectives and in understanding the management of computer-based development. Early experience of support of the software shows that the effort expended in achieving the design objectives of reliable and maintainable software has been justified and will be repaid many times over in the future.

ACKNOWLEDGEMENTS

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B 3-21

A FAST AND CLEAR COLLISION AVOIDANCE MANOEUVRE

by Cornelis DeWit ,
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O. ABSTRACT.
Let A and B be two course crossing ships under way with a danger of
collision. Applying rules 15 and 17 of the International Regulations
for Avoidance of Collisions at Sea (IRACS), let A be obliged to take
evading action, while B is initially obliged to maintain course and speed.

Denoting A's and B's positions at time t as $\underline{x}(t)$ and $\underline{y}(t)$, the co-
-ordinate axes are so selected that - see figure 1 -
(i) A is at the origin at time $t = 0$, so $\underline{x}(0) = \underline{0}$ and
(ii) A is approaching steadily along the X_1-axis, so
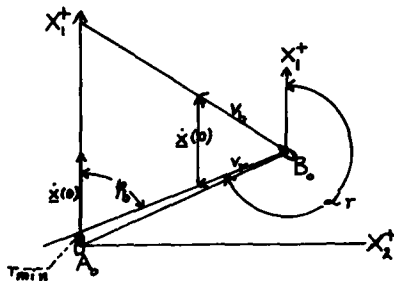$$\underline{\dot{x}}(0) = (v_a(0) \quad 0)' , \quad \underline{\ddot{x}}(0) = \underline{0} .$$

Figure 1.
Two course crossing ships A and B with a danger of collision

A's collision avoiding manoeuvre (c.a.m.) will consist of a certain
rudder angle input $\{\delta(t)\}$ with a constant full power propellor thrust.
$\{\delta(t)\}$ is defined by
$\delta(t) = 0°$ for $0 \leq t < t_1$,

$\delta(t) = + 20°$ (starboard helm) for $t_1 \leq t < t_2$,

$\delta(t) = - 20°$ (or $-10°$ occasionally) for $t_2 \leq t < t_3$,

$\delta(t) = + 20°$ for $t_3 \leq t < t_4$,

$\delta(t) = - 20°$ for $t_4 \leq t < t_5$,

$\delta(t) = 0°$ for $t \geq t_5$.

C 1-1

At time t_5 A should be back on her former track, heading her former course. A's track as a result of this rudder input is shown in figure 2.
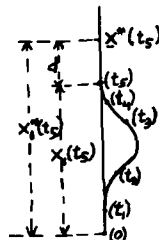

Figure 2.

At time t_5 A has a certain arrearage d to the position that A would have had without the c.a.m.:

$$d = x_1^*(t_5) - x_1(t_5) \quad \text{with} \quad x_1^*(t_5) = x_1(0) + v_a(0) t_5 .$$

This arrearage d is needed for A to keep sufficiently clear from B.

This paper presents an algorithm to evaluate this needed arrearage and the corresponding switching times t_1, t_2 etc.
If d appears to be too large, the c.a.m. consists of a sufficiently wide loop around B's stern.

The entire procedure was preprogrammed for a given ship with known dynamics. This program was tested on a wide variety of cases.

1. INTRODUCTION.

Consider the following situation, occurring in open sea with a good visibility.
At time $t = 0$ the own ship A has detected a course crossing ship B with a danger of collision. B is approaching at a constant relative velocity of magnitude v_r and direction α_r. B's relative bearing φ_b, as seen from A, is less than two points aft the beam, i.e.

$$4° < \varphi_b < 112.5° .$$

Prior to $t = 0$, a radar plot has been made, revealing that B's distance of closest approach r_{min} is less than a preset value r_o, leading to the conclusion that there is a danger of collision.
In the given situation A is obliged to take evading action while B is initially obliged to maintain course and speed. (The quantities v_r, α_r, φ_b and r_{min} are shown in figure 1.)
In a recent paper - see [1] - a method was presented to evaluate a "time optimal collision avoiding manoeuvre". This method had the following characteristics.
(1) The ship's dynamics were modelled by the following set of differential equations :

C 1-2

$$\dot{x}_1 = u_1 \cos \Psi - u_2 \sin \Psi \quad , \tag{1.1.a}$$

$$\dot{x}_2 = u_1 \sin \Psi + u_2 \cos \Psi \quad , \tag{1.1.b}$$

$$\dot{\Psi} = \omega \tag{1.1.c}$$

$$\dot{\omega} = - a \omega - b \omega^3 + c \delta \quad , \tag{1.1.d}$$

$$\dot{u}_1 = - f u_1 - W \omega^2 + S \quad , \tag{1.1.e}$$

$$u_2 = - r_1 \omega - r_3 \omega^3 \quad . \tag{1.1.f}$$
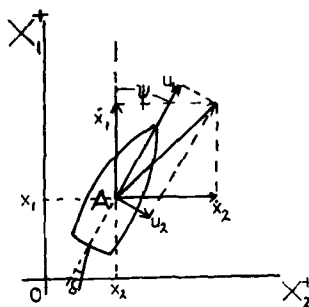
Figure 3.

Notations : $\underline{x} = (x_1 \quad x_2)'$, $\underline{\dot{x}} = (\dot{x}_1 \quad \dot{x}_2)'$: A's position and velocity,

Ψ , ω : A's course and rate of turn ,

u_1 , u_2: A's forward and starboard beam velocity .

δ : rudder angle .

All of these quantities are shown in figure 3 .

(2) To avoid collision, A carries out a bang-bang rudder manoeuvre $\{\delta(t)\}$, the graph of which is shown in figure 4 .

Figure 4.

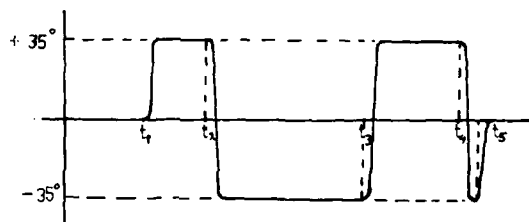The switching times t_i , $i = 1(1)5$, were determined by the following conditions :

(a) $x_2(t_5) = \Psi(t_5) = \omega(t_5) = 0$, (1.2)

(b) B's closest approach to A has to be equal to r_0 ,

(c) The total duration of the manoeuvre, up until the moment of closest approach or until t_5 , if that moment would come later, has to be minimal.

The numerical algorithm to evaluate t_1 , t_2 etc. was tested on a number of cases. The outcome of these tests gave rise to a subdivision into two classes.

(a) In most cases the starting time t_1 appeared to be as early as possible The entire loop was described way ahead of the time of closest approach. Figure 5 gives a view of the evading procedure in this case.

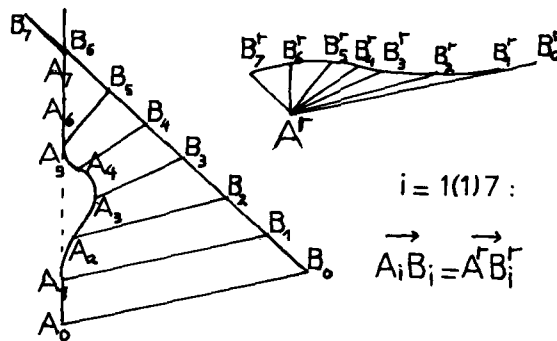Figure 5.
As a result of A's delaying manoeuvre
B passes well ahead of A.

(b) If B is approaching from a direction close to the bow, the c.a.m. is postponed until a later time, resulting in an evading loop around B's stern. Figure 6 shows what principally happens.
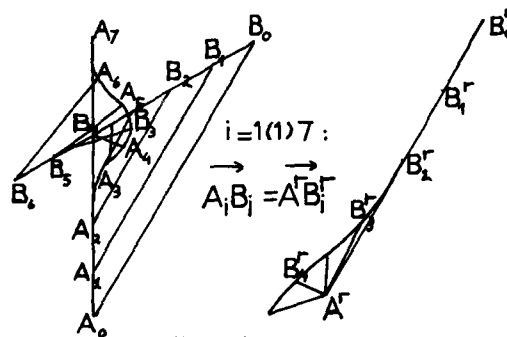

Figure 6.

We shall now pay some more attention to case (a). For times $t \geq t_5$ the ship is back on her former track, however with a certain arrearage[5]:

$$d(t) = x_1^*(t) - x_1(t) \quad \text{with} \quad x_1^*(t) = v_a(0) \, t \, . \qquad (1.3)$$

$$(v_a(0) : \text{A's speed at time} \quad t = 0.)$$

This arrearage enables A to let the other ship B pass ahead of her at a sufficient distance. Reversing this argument, we can evaluate d_n as a necessary arrearage to guarantee a closest distance from A to B at the amount of r_o at least. Setting the starting time t_1 as early as possible - in this study I selected $t_1 = 1$ min. - this value d_n and the "final loop conditions" (1.2) can be used to determine the switching times t_2, t_3, t_4 and t_5.

According to the dynamic model as well as to practical experience, the ship's forward speed at time t_5 has not yet regained its former value $v_a(0)$. Properly speaking, this means that we have

$$\text{for} \quad t > t_5 \quad : \quad d(t) > d(t_5) \, . \qquad (1.4)$$

So if we set a lower bound to $d(t_5)$ to guarantee a certain clear distance r_o at a later time, counting on an arrearage equal to $d(t_5)$, the actual clear distance will be greater than r_o.

2. SOME DETAILS OF THE MODIFIED DYNAMIC MODEL.

Compared to the dynamic model that was used in the first study, a few modifications were applied.
In the first place the rudder angle's coefficient c in (1.1.d) was replaced by

$$c^* = c_1 + c_2 \, u_1 \, .$$

This means that we take account of a decrease in the turning moment, caused by the speed reduction, which in its turn is a result of the ship's rate of turn.
Secondly a maximal rudder angle of $35°$ is rather unpractical in open sea. We used $20°$ as a maximum for $|\delta|$ instead.
The dynamic model can now be worked out.

$$\dot{x}_1 = u_1 \cos \Psi + (r_1 \omega + r_3 \omega^3) \sin \Psi \, , \qquad (2.1.a)$$

$$\dot{x}_2 = u_1 \sin \Psi - (r_1 \omega + r_3 \omega^3) \cos \Psi \, , \qquad (2.1.b)$$

$$\dot{\Psi} = \omega \qquad , \qquad (2.1.c)$$

$$\dot{\omega} = - a \omega - b \omega^3 + (c_1 + c_2 u_1) \delta \, , \qquad (2.1.d)$$

$$\dot{u}_1 = - f u_1 - W \omega^2 + S \, . \qquad (2.1.e)$$

Units : times in minutes, lengths in nautical miles, angles in radians.

This dynamic model corresponds to a 9 000-tons cargo carrier with a service speed of 15 knots.
Expressed in the appropriate units, the various parameters were given the following values :

$r_1 = 0.0375$, $r_3 = 0$, $a = 1.084$, $b = 0.62$, $c_1 = 1$, $c_2 = 10.212$,
$f = 0.86$, $S = 0.215$, $W = 0.07$.

The 15 knots' service speed means an initial value for u_1 of $u_1(0) = 0.25$.

Defining the "smoothened" signum function as

$$sig(t) = t/(t^2 + 10^{-4})^{\frac{1}{2}} , \qquad (2.2)$$

the following function was selected for the rudder angle :

$$\delta(t) = 0.0875(sig(t-t_1+0.1)+1)(sig(t_5-t-0.1) \prod_{i=2}^{4} sig(t_i-t+0.2) . \quad (2.3)$$

Figure 7 shows the graph of this function for an arbitrary set of values for t_1 until t_5 .
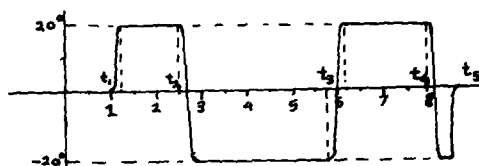

Figure 7.
Graph of the rudder angle function $\delta(t)$
with $t_1 = 1$, $t_2 = 2.5$, $t_3 = 5.8$, $t_4 = 8$, $t_5 = 8.7$.

Adopting this function implies the assumption that it takes 0.4 minutes or 24 seconds to move the rudder from $\pm 20^\circ$ to $\mp 20^\circ$.

3. EVALUATION OF THE C.A.M.'S CHARACTERISTICS .

For the time being we shall shift the origin to t_1 . If we now select t_2, t_3, t_4 and t_5, the set of differential equations (2.1) can be numerically integrated, using the rudder function as given by (2.2&3) and taking as initial conditions

$$x_1(0) = x_2(0) = \Psi(0) = \omega(0) = 0 , \quad u_1(0) = 0.25 .$$

The outcome is a set of values for x_1 , x_2 etc. at time t_5 .
For an arbitrary value of t_2 – within a certain range – the values of t_3, t_4 and t_5 are implicitly determined by the final conditions

$$x_2(t_5) = \Psi(t_5) = \omega(t_5) = 0 .$$

The following lines are a brief description of a method to evaluate t_3 , t_4 and t_5 .
Introducing a vector $\underline{y} = (y_1 \ y_2 \ y_3)'$ and taking

$$t_3 = t_2 + y_1^2 , \quad t_4 = t_3 + y_2^2 , \quad t_5 = t_4 + y_3^2 , \qquad (3.1.a,b,c)$$

the final values of x_2 , Ψ and ω become functions of $\underline{y}$. Defining

$$f(\underline{y}) = (x_2(t_5))^2 + (\Psi(t_5))^2 + (\omega(t_5))^2 , \qquad (3.2)$$

we can find the appropriate value $\widetilde{\underline{y}}$ – satisfying $f(\widetilde{\underline{y}}) = 0$ – by means of minimization of f with a minimizing procedure.

C 1-6

This minimization was carried out for $t_2 = 1(0.25)2$. After each mini-
-mization t'. rrearage d at time t_5 was also evaluated :

$$d = 0.25 \ t_5 - x_1(t_5) \ . \qquad (3.3)$$

The result is exposed in table I .

Table I .
(t_i in minutes, d in nautical miles)

t_1	t_2	t_3	t_4	t_5	d
0	1	3.16	4.60	5.22	0.23
0	1.25	3.98	5.79	6.46	0.37
0	1.5	4.81	6.98	7.67	0.55
0	1.75	5.60	8.15	8.90	0.78
0	2	6.51	9.35	10.02	1.09

Applying the least square residuals technique, these results can be well
enough represented by the following set of interpolating formulae, valid
for an arbitrary value of t_1 .

$$t_2 = (0.4815 + \sqrt{(1.7828 \ d - 0.25165 \ )}/0.8914 + t_1 \ , \qquad (3.4.a)$$

$$t_3 = 0.16(t_2 - t_1)^2 + 2.848(t_2 - t_1) + 0.16 + t_1 \ , \qquad (3.4.b)$$

$$t_4 = 0.0686(t_2 - t_1)^2 + 4.5623(t_2 - t_1) - 0.0263 + t_1 \ , \quad (3.4.c)$$

$$t_5 = - 0.2514(t_2 - t_1)^2 + 5.5703(t_2 - t_1) - 0.1043 + t_1 \ . \quad (3.4.d)$$

Figure 8 shows the graphs of $\delta(t)$, $\Psi(t)$, $\omega(t)$ and $u_1(t)$ for a c.a.m.
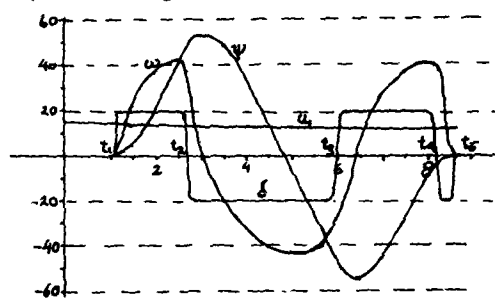loop with $t_1 = 1$ and $t_2 = 2.5$.

Figure 8.

δ : rudder angle (degrees)
Ψ : course deviation from schedule (degrees)
ω : rate of turn (degrees/minute)
u_1 : ship's forward velocity (knots)

4. EVALUATION OF THE NEEDED ARREARAGE.

At the start of the procedure, the following quantities are assumed to be known :

r_o : lower bound for the allowed closest mutual approach,

d_o : initial value of the distance AB , $d_o = ||\underline{y}(0)||$,

φ_b : B's relative direction as seen from A at time $t = 0$,

v_r : B's relative speed at time $t = 0$,

α_r : B's relative course at time $t = 0$,

$\alpha_r^* \equiv \alpha_r - \pi$,

so, with $\underline{\dot{\Delta x}}_o = (\dot{\Delta x}_{1_o} \quad \dot{\Delta x}_{2_o})' = \underline{\dot{y}}_o - \underline{\dot{x}}_o$ we have

$\dot{\Delta x}_{1_o} = v_r \cos \alpha_r$, $\dot{\Delta x}_{2_o} = v_r \sin \alpha_r$.

We further denote

r_{min} : Least distance from A to B, assuming that both vessels maintain their course and speed,

r_c : B's distance to A when crossing A's rhumb line without a c.a.m. This initial situation is shown in figure 9.
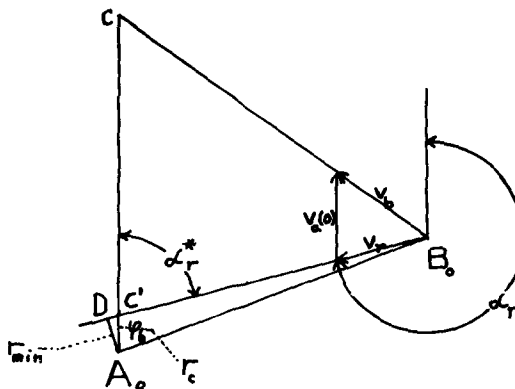
Figure 9.

It is now clear that

$$r_{min} = d_o \sin(\alpha_r^* - \varphi_b) \tag{4.1}$$

and $\qquad r_c = r_{min}/\sin \alpha_r^*$. $\qquad\qquad\qquad$ (4.2)

Remark : r_{min} and r_c follow the sign of $\alpha_r^* - \varphi_b$. So r_{min} and r_c are negative, if $\alpha_r < \varphi_b$, i.e. if B would have passed behind A's stern.

C 1-8

After having described an evading loop, we assume that A has regained her former speed. Now, with A and B both proceeding in the old directions with the old speed, B's relative velocity has also regained its old value. This means that B's relative track for A is a straight line, that intersects A's track at an angle α_r^* . (See figure 10)
In order to keep sufficiently clear from B, A should have a distance r_0 to B's relative track.
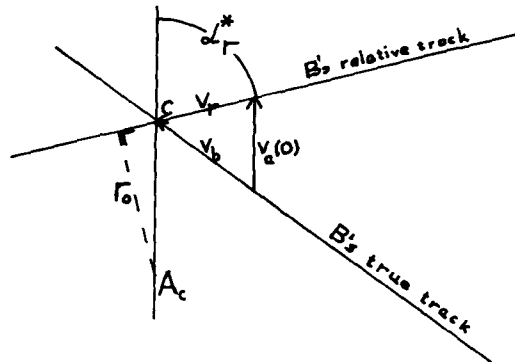

Figure 10.

So at the time, when B crosses A's course line at C, A's distance to C should be increased from r_c - before the $(t_1 - t_5)$-loop - to $r_0/\sin \alpha_r^*$ after the evading loop. Thus the needed arrearage is

$$d_n = r_0/\sin \alpha_r^* - r_c \, .\qquad\qquad (4.3)$$

5. THREE AVOIDING STRATEGIES.

Considering the (t_1-t_5)-loop, the ship's maximal deviation from her original course grows rapidly for increasing values of d . We therefore set an upper limit to d_n at the amount of 0.7 nm. This corresponds to a maximal change of heading of 55°.
We thus come to the proposal of three evading strategies.
(1) If the necessary arrearage in track for A to keep clear from B is not greater than 0.7 nm, we follow strategy No.1 :

$$\text{If } d_n \leqq 0.7 \text{ then Strat. No.1 .}\qquad\qquad (5.1)$$

The c.a.m. starts at t_1 = 1 min. The switching times t_2 until t_5 can then be evaluated from formulae (3.4.a) to (3.4.d). For pragmatic reasons, these values are rounded off to the nearest tenth of a minute.

If the necessary arrearage appears to exceed this 0.7^{nm}-limit, we select one of the strategies No.2 or 3, depending on whether or not r_{min} is positive. Stated formally :

C 1-9

If $d_n > 0.7$ & $r_{min} \geqq 0$ then Strategy No.2   and   (5.2)

If $d_n > 0.7$ & $r_{min} < 0$ then Strategy No.3 .   (5.3)

Before describing these strategies, we have to define t_{min} as the time, when A and B would have had their closest approach r_{min} without any evading manoeuvre. This moment follows from

$$t_{min} = d_0 \cos(\alpha_r^* - \varphi_b)/v_r .$$ (5.4)

(2) We shall now specify Strategy No. 2:

$$t_1 = t_{min} - 4 ,$$ (5.5.a)
$$t_2 = t_1 + 1.5 ,$$ (5.5.b)
$$t_3 = t_1 + 4.8 ,$$ (5.5.c)
$$t_4 = t_1 + 7 ,$$ (5.5.d)
$$t_5 = t_1 + 7.7 .$$ (5.5.e)

The rudder angle signal is + 20° for $t_1 \leqq t < t_2$ & $t_3 \leqq t < t_4$ and

$- 20^\circ$ for $t_2 \leqq t < t_3$ & $t_4 \leqq t < t_5$.

(3) If r_{min} is negative, we make a wider loop around B's stern, because B would have passed closely behind A without an evading manoeuvre. We achieve this by selecting a rudder angle of $- 10^\circ$ during the time interval between t_2 and t_3. The switching times are

$$t_1 = t_{min} - 4 ,$$ (5.6.a)
$$t_2 = t_1 + 1.5 ,$$ (5.6.b)
$$t_3 = t_1 + 7.4 ,$$ (5.6.c)
$$t_4 = t_1 + 9.7 ,$$ (5.6.d)
$$t_5 = t_1 + 10.5 .$$ (5.6.e)

The rudder angle signal is identical to the values in Strategy No.2 for the time intervals $[t_1, t_2)$, $[t_3, t_4)$ and $[t_4, t_5)$. However for $t_2 \leqq t < t_3$ the rudder angle signal is $- 10^\circ$.

Concerning the other ship B, her true track and motion are not relevant when it comes to deciding, which of the three evading strategies is to be selected. However, when the entire evading manoeuvre is precalculated, it is also important to calculate the time behaviour of the relative position vector

$$\Delta \underline{x}(t) = \underline{y}(t) - \underline{x}(t) .$$ (5.7)

We therefore need to know B's - assumed to be constant - true motion $\dot{\underline{y}}$, characterised by its magnitude v_b and its direction α_b . Considering the triangle of steady velocities, shown in Figure 11, we can easily derive these quantities from the following formulae :

$$h = v_r \sin \alpha_r^* , \quad p = v_r \cos \alpha_r^* ,$$ (5.8.a & b)

$$\beta_1 = arctg(p/h) , \quad \beta_2 = arctg((0.25-p)/h) ,$$ (5.8.c & d)

$$\alpha_b = \alpha_r + \beta_1 + \beta_2 , \quad v_b = \sqrt{((0.25 - p)^2 + h^2)} .$$ (5.8.e & f)
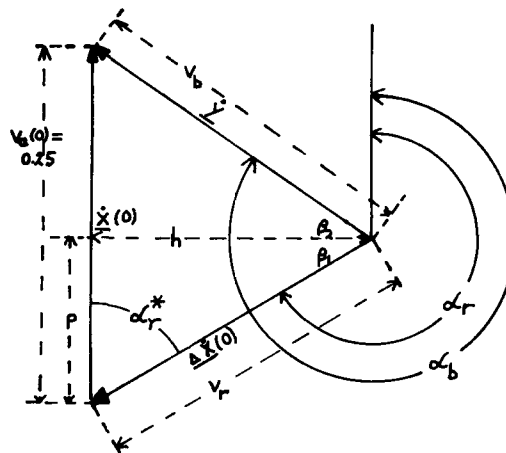
C 1-10

Figure 11.

6.EXAMPLES.

In this paragraph three worked out examples are presented of each of the three evading strategies. A's course is taken equal to 0° and A's initial speed is 15 knots, so $v_a(0) = 0.25$. For the safety boundary of the minimal mutual distance the value $r_o = 0.3$ nm was selected.

Example 1 : (See figure 12)

At 5 nm distance from A, B is approaching from a direction $\varphi_b = 60^{\circ}$ with a relative course $\alpha_r = 238^{\circ}$ and a relative speed $v_r = 0.25$ nm/min. Using (4.1), (4.2) and (5.4) we find

$$r_{min} = -0.18 \quad , \quad r_c = -0.21 \quad , \quad t_{min} = 20 .$$

From formulae (5.8.a) to (5.8.f) we can conclude that

$$\alpha_b = 299^{\circ} \quad , \quad v_b = 0.242 \text{ (corresponding to 14.5 knots)}.$$

The necessary arrearage follows from (4.3) : $d_n = 0.56$. In view of (5.1) we use strategy No. 1, so $t_1 = 1$. With (3.4.a) to (3.4.d) we find

$$t_2 = 2.5 \quad , \quad t_3 = 5.8 \quad , \quad t_4 = 8 \quad , \quad t_5 = 8.7 .$$

Evaluating A's and B's expected tracks. we find a minimal distance of 0.34 nm. Figure 12 shows these tracks as well as B's relative track, as seen on A's radar screen, if it is working in the "true bearing & rela- -tive motion'-mode.

C 1-11
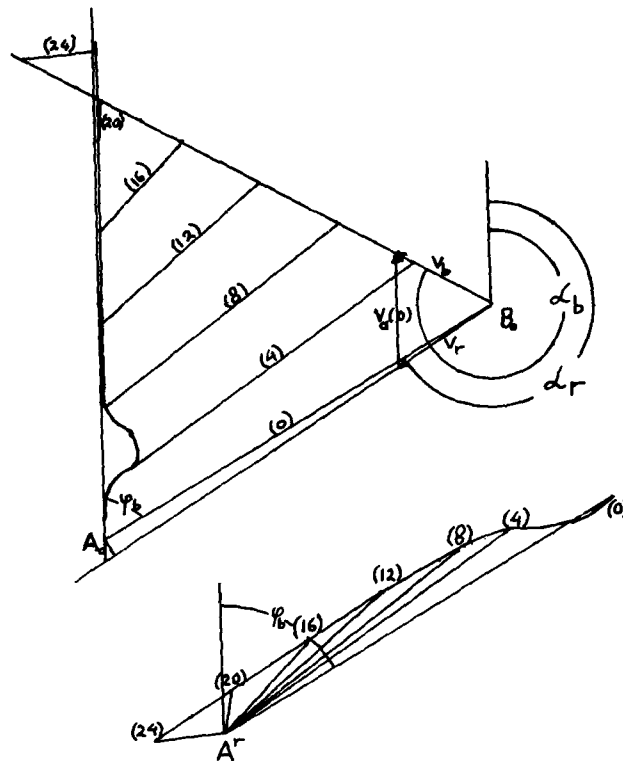
Figure 12 .

$d_o = 5$ nm , $\varphi_b = 60^o$, $\alpha_r = 238^o$, $v_r = 0.25$ nm/min $= 15$ knots .

$r_{min} = -0.18$ nm , $r_c = -0.21$ nm , $t_{min} = 20^{min}$, $d_n = 0.56$ nm .

Strategy No. 1 :

	$\delta(t) =$	
$t_1 = 1^{min}$	$\delta(t) =$	0°
$t_2 = 2.5^{min}$	$\delta(t) =$	$+ 20^o$
$t_3 = 5.8^{min}$	$\delta(t) =$	$- 20^o$
$t_4 = 8.0^{min}$	$\delta(t) =$	$+ 20^o$
$t_5 = 8.7^{min}$	$\delta(t) =$	$- 20^o$
	$\delta(t) =$	0°

Closest approach 0.34 nm expected at time $t_{min}^* = 21^{min}$.

C 1-12

Example 2: (see figure 13)

This is an example of strategy No. 2. The captions supply the numerical details.
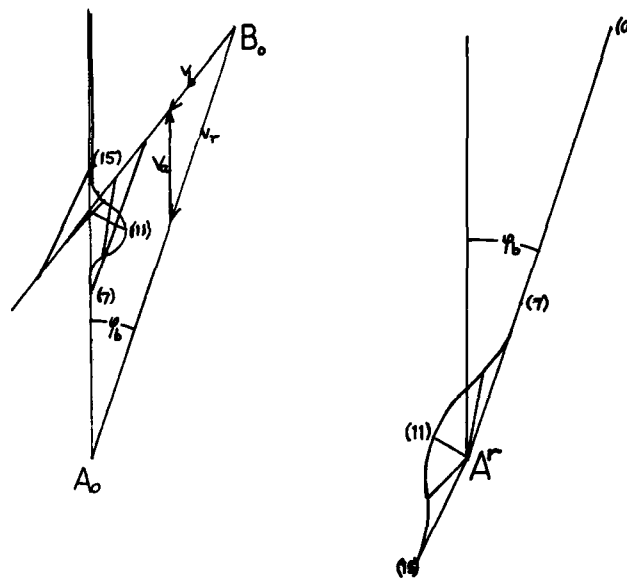
Figure 13.

d_o = 5 nm , φ_b = 18° , α_r = 198° , v_r = 0.45 nm/min ≈ 27 knots.

r_{min} = r_c = 0 , d_n = 0.97 nm , t_{min} = 11.1^{min} , α_b = 218° , v_b = 13.6 kn.

Strategy No.2 :

		$\delta(t)$ = 0°
t_1 = 7.1^{min}		
		$\delta(t)$ = + 20°
t_2 = 8.6^{min}		
		$\delta(t)$ = − 20°
t_3 = 11.9^{min}		
		$\delta(t)$ = + 20°
t_4 = 14.1^{min}		
		$\delta(t)$ = − 20°
t_5 = 14.8^{min}		
		$\delta(t)$ = 0°

Expected closest approach 0.43 nm at time t_{min}^* = 11.5^{min}.

Example 3 : (see figure 14)

Like in the previous case, the approaching angle α_r is rather small in
this example, so the arrearage is too large to be realistic. Moreover,
r_{min} and r_c are negative, so that the evasion is carried out according to
the third strategy. Numerical details of this example can be found in the
captions to figure 14.
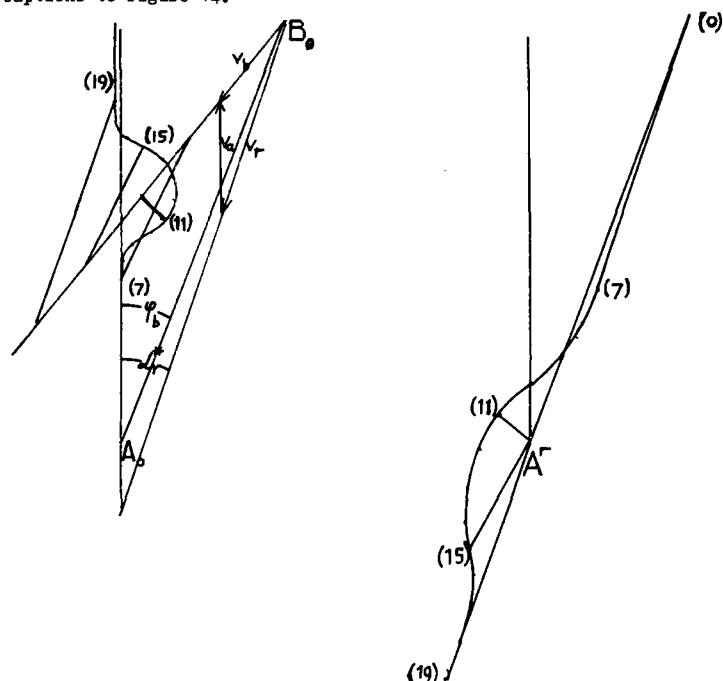
Figure 14.

d_o = 5 nm , φ_b = 20° , α_r = 198° , v_r = 0.45 nm/min = 27 knots,
r_{min}=-0.17 nm, r_c=-0.56 nm, d_n = 1.54 nm, t_{min}=11.1^{min},α_b=218°,v_b=13.6 kn.

Strategy No. 3 :

	$\delta(t)$ = 0°
t_1 = 7.1^{min}	$\delta(t)$ = + 20°
t_2 = 8.6^{min}	$\delta(t)$ = - 10°
t_3 = 14.5^{min}	$\delta(t)$ = + 20°
t_4 = 16.8^{min}	$\delta(t)$ = - 20°
t_5 = 17.6^{min}	$\delta(t)$ = 0°

Expected closest approach 0.41 nm at time t_{min}^* = 11^{min}.

7. CONCLUDING REMARKS.

In quality, the adopted model for the ship's behaviour has been found valid for a wide variety of ship types, from coastwise traders to large tankers. (See [2]). Of course, the various parameters r_1, r_2, a, b etc. can differ considerably.

Once these parameters are known, one can adopt reasonable values for the various input parameters and things can be entirely precalculated off line for a given ship.

Using these precalculations and counting on the present state of the art regarding possible computer facilities for on line operations, the neces--sary collision avoiding manoeuvre can be very well calculated within a few seconds. However, the author wishes to express his neutrality regar--ding the question, if the manoeuvre should be carried out by hand or automatically.

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A RADAR SIMULATOR WITH PROBABILISTIC MOVEMENTS
OF TARGET SHIPS FOR SHIP MANEUVER TRAININGS

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* Furuno Electric Co. Ltd., ** Kobe Univ. of Mercantile Marine

ABSTRACT

A radar simulator is newly designed and implemented. This simulator generates targets up to eight ships automatically which move probabilistically under computer control. The simulator deals with two models of target ships' movements. One is to simulate ships passing through a narrow channel. Another is to simulate the situation such that an own ship encounters with targets at all times, which purpose is trainings of collision avoidance by use of a radar indicator. The situations are effectively produced by some specified probabilistic variables. Hence, the trainings are not restricted by time, and the management of the situation difficulty on training is relatively easy.

INTRODUCTION

The role of the electronic nautical instruments is much important for safe navigation in the enviroment that vessels become large and fast and ship operations are fairly automated in recent years. Especially the radar is an essential equipment on large merchant ships according to the provision of the law, and in addition to improvements of radar navigators are required to have enough skill in dealing with it. As a result, many kinds of radar simulators have been developed as the simple and efficient trainers on the ground and now the STCW convention requires radar simulator training to navigators(1).

In this paper, we propose a simulation technique of radar simulator in which the movements of targets on the radar indicator are probabilistically controlled by a computer. The probabilistic method is profitable to generate situations automatically and eternally. In comparison of a radar simulator using this method with the conventional ones whose situations are set up by manual or by scenario as choosing one of situations prepared beforehand, this new simulator has characteristics that it is able to perform self-training and to evaluate generated situations by statistic parameters.

THE OUTLINE OF SIMULATOR ARRANGEMENTS

The radar simulator is illustrated as a block diagram in Fig. 1. The installation consists of three parts; the first is equipments in a simulator room to manipulate the simulator and to display the visual data, the second is the hybrid computer to control the simulator, and the third is the interfaces between the computer and some visual equipments.

The digital part of the general purpose hybrid computer has a main memory of 16 K words (16 bits word), and the standard execution time is 2 u sec. As input and output devices of the computer, there are a

line printer, a card reader, a cartridge disk unit and a console which
is a graphic display of storage tube type with a hard copy unit. In the
analogue part (including interface units between the analogue unit and
the digital unit), it is able to execute analogue arithmetics, A/D and
D/A conversions and logical arithmetics. On the simulator in mock-up
bridge a trainee is able to manipulate a steering wheel and an engine
telegraph and also is able to look at repeater compasses, an engine
r.p.m. indicator, a rudder angle indicator, a ship speed meter and a
standard radar indicator which is now possible to display maximum eight
targets but not to display coast lines in the absence of hardware units.
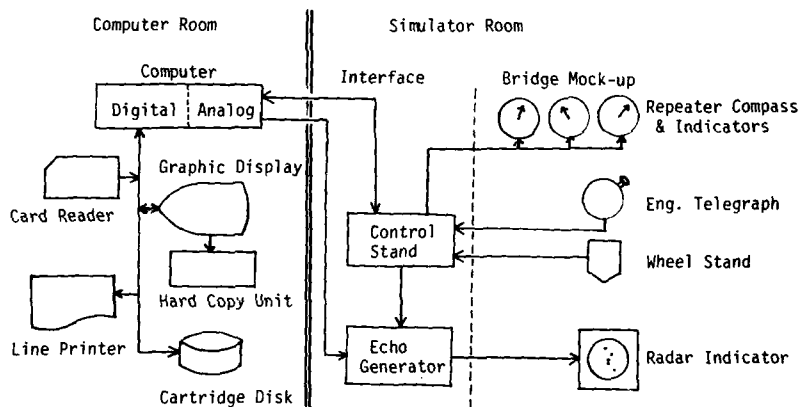
Figure 1.   A Block Diagram of A Radar Simulator.

PROCESS ON THE COMPUTER

The Outline of Process

Signals sent from the computer for the radar indicator and other
nautical instruments are required to be analogue by the hardware restic-
tion. Owing to the hybrid computer, it is relatively easy to transfer
or convert various information between simulator equipments and the
computer.

The input analogue signals for ship control are of an ordered rud-
der angle from the steering wheel and of an ordered engine r.p.m. from
the engine telegraph. The output analogue signals are of responsed mo-
tions that are rudder angle, engine r.p.m., ship speed, heading angle,
rate of turn and own ship position, and furthermore targets' positions
and the serial pulse signals to control pulse motors of repeater com-
passes. These input/output signals are converted analogue to digital
or digital to analogue in the analogue part of the hybrid computer
which is used as one of interfaces in this simulator system. The other
controls of simulation processes are done in the digital part, because
the software programming is much advantageous to develop and maintain
rather than the analogue patching.

In a ship handling simulator system(2) a calculation cycle of dig-
ital computations is desired to be less than 0.2 sec in order to drive
visual displays using pulse motors smoothly. Therefore the cycle of
the radar simulator is now set to be 0.1 sec in consideration of incor-
poration with the ship handling simulator in future.

Here the contents of processes at the digital part are shown ex-
cept the control of targets. The simulation program is devided into
three modules; a preparation module, a main loop module, and a termi-
nation module respectively.

The first module for preparation works in card-reading of initial
data, calculation of initial values, recognizing status of operational
buttons on the control stand, and preparation of recording of the sim-
ulation process. Especially in setting of initial conditions, auto-
matic setting of targets on the display is one of the characteristics
of this simulator. But full-automatic setting will restrict reproduc-
tibity and flexisibility of traffic situations and then the increase
of flexisibility will force an operator to do troublesome works of
target setting. Therefore, the initial data are given by the following
three ways;
1) The initial values on the simulation program: they contains system
constants of the simulator and fixed default values for some variables.
2) Inputs from card reader: these are used to specify statistical prop-
erties of targets. The simulator offers five kinds of own ship types,
and the type is specified by the values on cards.
3) Inputs from console: these give the initial values of pseudo random
number sequences for the probabilistic target's generation.

On the second module for main loop, there are three kinds of loop-
periods, namely, 0.1 sec, 1 sec, and 60 sec. The following processes
have the periods denoted in the brackets.
1) Calculation for own ship movement[0.1 sec]: own ship motion is ass-
umed to obey the second-order differential equations proposed by
Nomoto(3).
2) Calculation for present target's positions on the radar indicator
[0.1 sec].
3) Transmission of data of 1) and 2)[0.1 sec]: calculated logical data
for the radar indicator and others are converted into appropriate volt-
age levels, and transmitted to them. And serial pulse signals are also
transmitted to a pulse motor for the bearing control of own ship's head.
4) Generating targets discussed in the next section[60 sec].
5) Recording the simulation process[1 sec].

On the third module for termination, various equipments are recov-
ered to initial statuses, and the file of records of simulation is
closed when the simulation terminates normally.

Most of routines of the simulation program are described in
FORTRAN, and the total size of them is about 1000 steps in source form
and 13 K words in executable form.

Recording Simulation Data

The simulation data are available for evaluations of trainings, of
some criterions for collision avoidance, and so on. Gathering of data
is entirely carried out on the computer side and their output devices
are a line printer, a graphic display and a disk cartridge; we call
them as logging data, tracking data and disk data, respectively. The

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formers are used for monitorings on a simulation, and they are numerical records and visual records. The last is gathered for the sake of some analysis after the simulation.

Therefore disk data must be effective for the reproduction of a simulation, and the evaluation of trainings; for example the DCPA (Distance of Closest Point of Approach) and the TCPA (Time of Closest Point of Approach) are probably used for the analysis. Of course the output of these data in real time makes it possible to evaluate a training on the instant. Contents of these data are shown in Table 1, where the value in brackets denotes the time interval of output.

Table 1.   The Contents of Records

Data type	Contents
Logging data [1 min]	Elapsed time; Absolute position, Speed, Course of own ship; Relative position, Speed, Course, DCPA, TCPA of each target
Tracking data [4sec/target]	Trace of each target on graphic display with identifier
Disk data [10 sec]	Elapsed time; Absolute position, Speed, Course, Turn rate, Rudder angle, Rudder speed, Engine r.p.m. of own ship; Relative position, Speed, Course, DCPA, TCPA of each target

THE CONTROL OF TARGETS

On the Probabilistic Method

Generally, generations and movements of targets on the radar indicator are important and difficult problems. In conventional simulators whose purpose are mainly trainings of collision avoidances, situations of targets arrangement are specified by manual or scenario. It is considered that these methods are favourable to generate the intended and restricted situations in some limited time intervals, but that they have some problems to continue trainings or experiments for a long time and so on. For example, undesirable times are spent for setting the situations and moreover one of more important things is that it is comparatively difficult for conventional methods to change the grade of situations continuously(4).

The number of ships passing through a fairway, the time intervals of them, and positions passing through a channel are considered to obey simple probabilistic distributions(5,6). In view point of these laws the simulator proposed in this paper is designed to be able to generate and also change the traffic situations such that each target is subject to some probabilistic variables based on statistic properties. Fortunately it is easy for this method to control the situations automatically by a computer. In the generation of probabilistic variables, the computer creates pseudo random number sequences by the multiplicative

congruence method modulo 65536, each of which is bounded by an initial
random value. Hence, giving an initial random value to each event in-
dependently, the simulation is able to have reproductivity of the sit-
uations except the events depending upon trainee's responses. Conse-
quently effective trainings/experiments may be conducted by the repe-
tition and the partial modifications of situations through easy speci-
fications of distributions and their initial random values.

    Generally speaking about radar simulators, there are two contrary
requirements. One is that simulated situations must be produced faith-
fully to actual traffic flows, and the other is that the system must
be able to produce the particular situations available to collision
avoidance trainings. Answering these two requirements, two types of
simulation programs are proposed. They are called as follows for
simplicity.
        Type I : the simulation program of passing through a channel, and
        Type II : the simulation program of collision avoidance trainings.

Generation of Targets on Channel(Type I)

    Considerings the generation of targets passing through a channel,
the time intervals of ship's crossing a fixed view line on the channel
may submit to the exponential distribution, the positions passing on
the line may follow to the normal distribution and the ship speeds are
assumed to obey the uniform distribution. The simulation of a mathe-
matical model constructed by these probabilistic distributions has
reproductivity because the generated positions of targets are absolute
and the other events are independent of own ship movements. However,
it is difficult to realize probabilistic distributions in space and
time domain faithfully according to arbitrary given parameters, because
a channel is generally crowded traffic area, and then the number of
ships is large if all ones on the channel should be simulated. Hence it
is assumed that all of targets pass through in the opposite direction
against own ship in order to realize nearly realistic simulations with-
in the number of targets limited by hardware and that other targets
which have scarcely effect on the own ship's movements are not display-
ed on the radar indicator. In paticular a target passed through the
CPA(Closest Point of Approach) and located at 2 N.M. in the rear of
own ship is disappeared. Then it is utilized for the next coming
target.

    Even in such procedure is performed, the numbers of targets shown
simultaneously are insufficient for the specification of short time
interval. As the simulator offers eight targets at most, the queue of
targets yields a gap when the mean value of time intervals of targets'
approach is less than about 3.5 minutes although it depends on target's
speed and other factors. This figure 3.5 minutes is fairly large as
compared with real traffic along the coast. If the gap can be ignored,
it is possible to simulate real traffic flows partially. This problem
needs to get rid of hardware restrictions.

    Input parameters for the distributions are shown as followings.
1) The time intervals of targets arrivals to the entrance: the mean
value of the exponential distribution,
2) the mean and variance of target's position at the entrance and the
exit of a channel: the normal distribution as the width of channel,
and
3) the mean and variance of the uniform distribution of ship speed.

The initial random values for the generation of distributions are given from a console. As to 2), we consider that the distribution of positions passing a line at the entrance and the one at the exit are independent and each target proceeds on the straight line connecting two passing points. Therefore, the simulator will generate the situation that each target goes in parallel with direction of a channel if the same initial random values are given to both distributions at the entrance and the exit. The type I program does not simulate altering course and speed of targets. That is to say, as passing ships in a fairway follow the same direction as the fairway and go nearly straight with constant speeds generally, the simulation of altering course and speed seems to be non-realistic.

Generation of Targets in Case of Collision Avoidance(Type II)

This type does not neccessarily simulate realistic traffic flows because its main purpose is trainings of collision avoidance maneuvering. In this situation own ship simulated is going on a setting course given previously and at the same time targets are generated to force to encounter with her in spite of the present course. As for the target generation, the probabilistic factors considered here are time intervals of the generation, appearing positions, ship speeds, degree of concentration about the DCPA, time intervals of altering course, and angles of it. Describing the probabilistic factors in detail, following distributions are assumed.

1) The time intervals of the generation are based on the time to be trapped by radar and are considered to follow the Poisson distribution.
2) The positions of target's appearances are determined according to the normal distribution which is taken on a circle having the central point on the own ship.
3) The ship speed is the uniform distribution as same as type I.
4) Each target's course is determined such that she collides or nearly collides if both ships keep their courses and speeds because encountering situations must occur on trainings for collision avoidance maneuver. However if the DCPA of the own ship to the target is equal to zero at the begining of target's appearance, the own ship always comes into collision with the target. Therefore, the target's course is given such that the DCPA is distributed uniformly within the specified width, because a trainee may be able to predict the target's movement with repetition of trainings if the DCPA is always equal to zero. This means that even if a trainee should leave the encounter situation the case of collision-free may occur and if otherwise the own ship may collide. Furthermore this may make difficulties for a trainee to predict the movements of targets and to decide the suitable maneuvering of the own ship.
5) Each ship changes its course and speed in the actual sea according to the intention of a navigator and other reasons. Furthermore, rules of the road affect the managements of ship's course and speed according to the relations of the obliged vessels and the burdened vessels. Taking into consideration of these factors affecting ship's course and speed, it is difficult to design a computer program simulating these situations. On the other hand a model such that each target does not change its course and speed entirely restricts flexibility of traffic situations. In this paper, considering that the altering course is a usual action and also random course changings in some degree look like effective for trainings, it is assumed that the time intervals of altering course follow to the Poisson distribution and the angles of those follow to the uniform distribution for simplicity. Concerning

the altering of speed, it is not simulated because ships hardly alter
their speed on open sea except for urgent cases.

Note that parameters of 1) and 4) are dominant factors in the
situation difficulty.

APPLICATIONS AND EXAMPLES

How to Utilize

Applications of two kinds of simulation programs are shown as
follows.
For training or education---
    Type I : the training of passing through a narrow channel,
    Type II : the training of collision avoidance including the ship
            maneuver and the radar plotting.
For analysis---
    Type I : the design and the evaluation of channels, for example,
            the assessment of accidents,
    Type II : the evaluation of the criterion for collision avoidance etc..

Type I should be used for trainings of passing through a narrow
channel includind position keeping. On training of collision avoidance
in type I, though it is possible to simulate situations encountering
with ships in opposite direction, the own ship is able to avoid targets
easily and this is not suitable for the standard training of collision
avoidance. On the other hand, type II simulates traffic flows in open
sea and possible trainings using it are
1) the operation of radar equipments in common with type I,
2) the exercise of radar plotting,
3) the collision avoidance maneuvering including 1) and 2), and
4) the composite training of ship handling including a setting to a
scheduled route, a watch work and so forth.

In order to analyze simulation data, it is required to gather many
kinds of trainings. The data recorded in the system contain various
items for the general purpose. The examples of analysis by using disk
data are
1) the play back of the simulation which is in real time speed or in
altering speed,
2) the marking for trainees,
3) the evaluation of collision avoidance,
4) the determination of the criterion for collision avoidance (See the
next), and
5) the design and the evaluation of narrow channels on type I.

The Examples of the Simulation

Fig. 2 is an example of type I. Own ship keeps her course as 0°.
A mark for identification is given for each target at the generation
on graphic display.

On the other hand, Fig. 3 is tracking data of type II , and Fig. 4
is the true motion diagram corresponding to Fig. 3 made from disk data,
where each target is marked every five minutes by delimiters. In this
example, the trainee is informed the scheduled course (0°) and own
ship's type (the bulk carrier of 240 meters here), and he is instructed
to handle only by the radar with controls of a steering wheel and a
main engine. The function of altering course is suppressed here.

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Here, we show an analytic example which propose a method to evaluate the criterion for a collision avoidance. The TCPA and the DCPA in disk data are used. Fig. 5 denotes the relation that a value of the DCPA at A is equal to zero and then a collision should occur if this situation goes on but there is time enough to avoid, and B is on the DCPA axis but there is a room in distance. If own ship and each target keep their present courses and speeds, then a parallel line with the TCPA axis is drawn as C. If the point on C goes on, then the line passes a critical area. Hence when ship maneuvering is ideal in a sence, there exists an inviolated area like a hatching section in Fig. 5. Fig. 6 shows the relation of the TCPA-DCPA corresponding to the example of Fig. 3. In this example, the trainee keeps the DCPA of about 1 N.M.. By gathering examples of these ideal trainings, we will be able to decide the form of the inviolated area. This might make a good criterion for collision avoidance maneuver.

RADAR SIMULATION

Identifiers of ⟶

target ships

0'   5'

Channel width:
  1.5 miles

Mean time of arrivals:
  5 minutes

Mean speed of targets:
  20 knots

Figure 2. An Example of Type I.

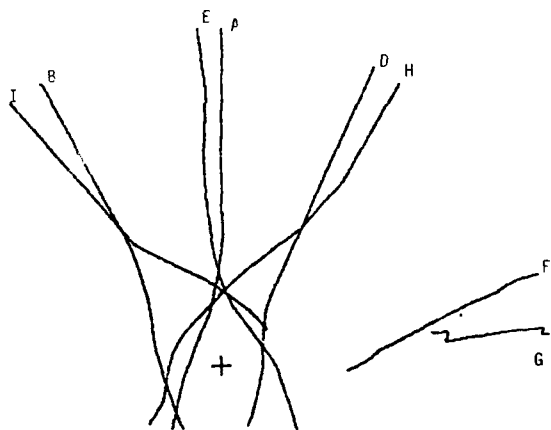RADAR SIMULATION

0'   5'

+ :Own ship position

Figure 3. An Example of Type II (Tracking Data).
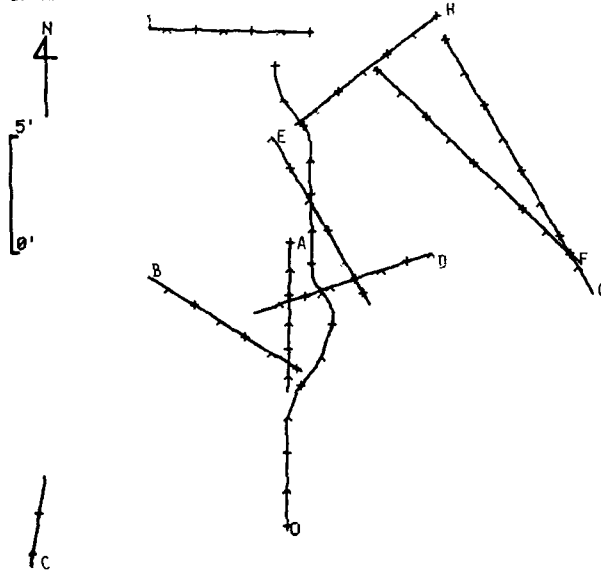C 2-8

ABSOLUTE PLOTTING
-DATAAE-

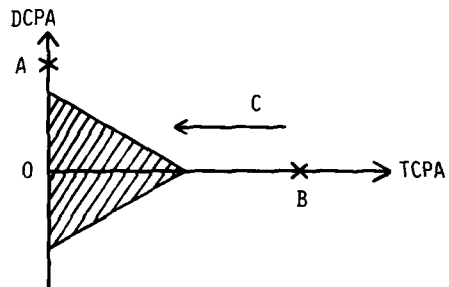Figure 4. A True Motion for the Example of Figure 3.

Figure 5. An Illustrative Relation of the TCPA-DCPA.
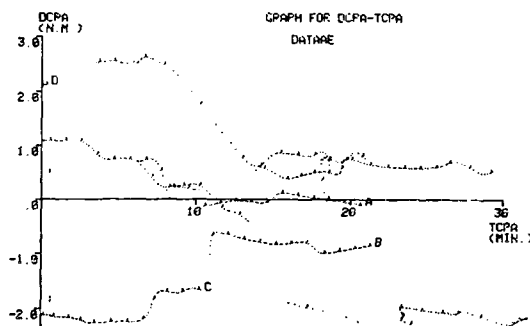
Figure 6. A Relation of the TCPA-DCPA for the Example of Figure3.

SUMMARY

This radar simulator is capable of the trainings of passing through a narrow channel and collision avoidance, and of the analysis related to them if neccesary. Especially it will be effective in the educational usage.

As the method of target's generation is probabilistically, there exists one advantage that the setting situations become variously, but how to decide "good" situations is a remaining problem. Selection of situations has serious influence on the effectiveness of trainings, and therefore data of various trainings must be saved and analyzed in order to utilize well. It is of interest that the movements of targets are affected by various factors besides statistical properties. For example, targets including own ship may interfare mutually and their movements must be obeyed under some rules. This simulator has a problem that traffic flows on narrow channels are not expressed throughly on account of hardware restrictions. Then, one solution for this problem is the utilization of a general purpose graphic display with the dedicated computer to control it.

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Figure 1 -   Ship Propulsion Mathematical Model

Diesel Engine

The model calculates the delivered torque as a function of speed and rack posi-
tion. The torque is taken from the torque map delivered by the engine in stationary
conditions, taking into account the engine windmilling conditions.
Torque rate limiting action due to the turbo-blower dynamics is simulated limiting
the actual torque rate when this superates a threshold function of the previous tor-
que value.

Diesel Engine Speed Governor

The model of the diesel engine speed governor consists in a subtraction node
between the set and present speed; the output of the node modifies the position of
the fuel rack with a proportional and integrative action. The maximum rack position
is limited according to the actual speed set. The speed set varies, according to the
control schedule, with a constant rate to simulate the dynamics of the speed setting
motor.

Gas Turbine

The model calculates the delivered torque as a function of throttle position
and turbine speed. The torque is calculated as a function of the fuel consumption
and turbine speed, extrapolated for the values of negative torque (turbine at idle
in windmilling condition). Between the throttle fuel function and the torque/speed/
fuel map a time constant function of the fuel consumption is provided in order to
simulate the time lag introduced by the speed governor of the gas generator.
The throttle position rate is limited in order to simulate the behaviour of the tur-
bine power lever actuator electronics.

Reduction gear

The reduction gear is considered as an ideal mechanical energy transformer according to the following relations:

(1) $\dfrac{N_2}{N_1} = \dfrac{Q_1}{Q_2} = r$

N_1, N_2 primary/secondary speed
Q_1, Q_2 primary/secondary torque
r reduction ratio

The reduction gear friction losses are taken into account together with the losses due to shaft driven pumps as a function $Q_R = Q_R (N)$ of the shaft speed.

Propeller pitch operation

Propeller pitch actuation rate is function of the delivery of the pumps.
The shaft driven pump delivery is function of the shaft speed, whilst the delivery of the motor driven pump is considered constant.
In the simulation, the influence of the oil pressure on the pump delivery has not been considered.

Propeller

To calculate the propeller torque and thrust the following formulas are used:
(2) $Q_E = \rho \cdot bre \cdot KQ.D^5.N^2$ propeller torque
(3) $T_E = \rho \cdot btd \cdot KT.D^4.N^2$ propeller thrust
KQ and KT are respectively the coefficients of the torque and thrust of the isolated propeller. These coefficients are function of the propeller pith and the advance coefficient J.
The meaning of the remaining symbols is as follows:
D: propeller diameter   N: shaft speed
ρ: sea water specific mass   V: ship speed
The advance coefficient is defined by the following formula:
(4) $J = (V.bwf)/(N.D)$
As the reversal of the ship's motion is obtained through the propeller pith change, the shaft speed is kept higher than a minimum value and the coefficient J value is always between the limits $- 1,4 + 1,4$.
The coefficients bre, bwf and btd (hydrodynamic coefficients normally function of the speed V), modify the propeller equations for the hull influence as follows:

bre - Torque Coefficient - The torque coefficient takes into account the proximity of the propeller to the hull which increases the propeller friction in the water; therefore the torque absorbed by the propeller in its true installation is greater than that absorbed by the isolated propeller.

btd - Thrust Coefficient - The thrust coefficient takes into account that the propeller when rotating attracts the water in the space which separates the propeller from hull and push it astern. The water flow   near the hull increases its resistance to the motion   in relation to the resistance presented in towing conditions. The increase in resistance due to this effect is considered as a reduction of the propeller thrust.

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bwf - Wake Coefficient - The wake coefficient takes into account that
the water in which the propeller rotates is not stationary but is dragged into mo-
tion by the hull itself; the propeller has to move in the water with a lower advance
speed than that of the ship.

Hull Resistance

The function of resistance to the ship's motion both for ahead and astern mo-
tion, is obtained from the tank tests of the ship model.

Total Mass Of The Ship

The total mass of the ship is considered to be the mass of the ship plus an
estimated term,function of the water mass driven into motion by the hull.

Control System

The control system, acts on the propeller pitch demand and the gas turbine
throttle demand or the diesel speed demand,(according to the type of machine in pro-
pulsion) according to the position of a ship speed control lever,taking into account
actual values of propeller pitch and speed.
As the control system operates through a process computer, there is no difference
between the control algorithms relevant to the control system and those used in the
simulation.

Torque and Thrust Balance Equations

The models described previously are linked together by the following differen-
tial equations:

(5) $\quad Q_M - Q_E - Q_R = \dfrac{I}{2\pi} \cdot \dfrac{dN}{dt}$ $\qquad$ torque equation

(6) $\quad n.T_E - R = M \cdot \dfrac{dV}{dt}$ $\qquad$ thrust equation

The following definitions apply:
n = number of shafts in propulsion (one or two)
Q_M motrix torque
I   moment of inertia of the rotating masses
R   hull resistance to motion
M   total mass of the ship.

Further Models Details

Model design has been developed first to achieve an optimal control system and se-
condary to foresee ship performance response.
One of the aims of the control system is to allow fast and safe propulsion plant
operation in every operating condition. The variations in operating conditions are
due to variations of displacement, hull fouling, engines wearing. These variations
permit not to take into account parameters which present lower changes.

For example the hydrodynamic coefficients of the propeller have been kept constant
to the average value (considering also that they have difficult measurements and
there are difficulties in verifying them during the sea trials of the ship).

Simulation Implementation

The simulation has been carried out on a minicomputer programming in
Basic and Assembler languages. The algorithms relative to the machinery and the ship
are written in Assembler, whilst the algorithms of the control system and the running
structure of the program and the print subroutines are in Basic; this choice was done
to permit easy modifications of the control system algoritms whilst retaining hight
computation speed of the machinery algorithms.
The calculation of the integrals has been made with the rectangles formula.
The sampling period has been chosen in function of the speed rate of the variables;
it is 0.2 seconds for the algorithms involved in the torque equation and 0.5 seconds
for those involved in the thrust equation and in the model of the pitch actuator.

SIMULATOR FOR PROPULSION CONTROL SYSTEM TESTING

The automatic control system is computer based. It provides the automatic con
trol of the propulsion machinery, and the automatic starting/stopping both for the
diesel and gas turbine engines. The control system also carries out change-over se-
quences in a fully automatic mode. During such sequences the manual controls are
still operative, in order to allow the operator to interrupt an automatic sequence
and keep on doing it manually. All that is done by a control system which is forced
to consider the greatest number of possible propulsion system configurations (false
indication caused by sensor failures are considered also).

In order to test the control system completely and truly before carrying out
the sea trials, a simulator of the machinery of one of the ship's shafts (the two
shafts are the same and independent from each other) has been designed.
The simulator receives the commands from the automation plant under test and provides
feedback signals which represent the functioning conditions of the machinery elabo-
rated with the same dynamics as the actual machinery.

Starting and Stopping of the Diesel Engine

The model calculates the torque delivered by the engine during the start phase and
the conditions which cause the change-over from engine not running to engine running
models. Engine running conditions are those taken into account in the control system
design. The engine not running consists in the delivery of a constant negative torque.
The model of the engine running calculates the torque delivered by the starting
air actioning the cylinders.   The torque is function of the speed and
the air pressure. The engine is considered running when, with fuel-on condition
it reaches the idle speed.

Starting and Stopping of Gas Turbine

The starting model of the turbine calculates the speed of the gas generator and
the temperature of the power turbine inlet gas as a function of present speed, with
starter, igniters and fuel controls in "on" condition.
The turbine is considered as running when the gas generator speed reaches the "flame

on" speed with igniter and fuel on (combustion without self-sustainment) or when
the speed of the gas generator reaches the idle value.
When the turbine is running, the model developed for the design of the control
system is turned on; otherwise the stopped engine model, which foresee a negative
torque speed function, is turned on.

Friction Clutch

The condition of the friction clutch influences the differential equation used
for the speed calculation. In the friction clutch engaged condition, equation (7)
is used.

$$(7) \quad Q_D + (Q_T) - Q_E = \frac{I_A + I_D + (I_T)}{2\pi} \cdot \frac{dN_A}{dt} \quad ; \quad N_D = N_A$$

The magnitudes influenced by the state of the synchronizing clutch are indicated
in brackets.
With the friction clutch open or slipping, the equation (7) transforms into equation
(8).

$$(8) \quad Q_D - Q_F = \frac{I_D}{2\pi} \cdot \frac{dN_D}{dt} \quad ; \quad Q_F - Q_E = \frac{I_A}{2\pi} \cdot \frac{dN_A}{dt}$$

Where:

N_D	diesel speed	Q_D	diesel torque
N_A	shaft speed	Q_F	slipping clutch torque
I_D	diesel engine moment of inertia	Q_E	propeller torque
I_A	shaft moment of inertia		

The torque Q_F is the torque through the clutch; the module of Q_F is function of air
pressure P (the clutch is air operated); the sign of Q_F is that of the difference
$N_D - N_A$, considering NA the speed of the output shaft of the clutch.
Pressure P, when the clutch closure is commanded, increases according with a sche-
dule, until it reaches the stationary "on" value.
When, with pressurized clutch, it is verified that $N_D = N_A$, instead of equation (8),
equation (7) is used. When $Q_D > Q_F$ (assuming that the inertia of the diesel engine
in far lower than that of the reduction gear) the clutch begins to slip and instead
of equation (7) equation (8) is used.

Synchronizing Clutch

In the synchronizing clutch disengaged condition the turbine is independent from
the shaft; the differential equation which calculates the speed is the following:

$$(9) \quad Q_T = \frac{I_T}{2\pi} \cdot \frac{dN_t}{dt} \qquad \begin{array}{ll} I_T & \text{turbine inertia} \\ Q_T & \text{turbine torque} \\ N_T & \text{turbine speed} \end{array}$$

When the clutch is engaged, the speed of the turbine, equal to the shaft speed, is
calculated with the following formula:

$$(10) \quad Q_T + (Q_D, Q_F) - Q_E = \frac{IA + IT + (I_D)}{2\pi} \cdot \frac{dN_A}{dt} \quad ; \quad N_T = N_A$$

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The magnitudes influenced by the state of the friction clutch are indicated in brackets.
The model of the clutch passes from the disengaged condition to the engaged condition when, having the clutch been preset to engagement, the speed of the turbine tends to be greater than the output shaft speed connected with the reduction gear .
The clutch changes from the engaged condition to the disengagement when, as the disengagement is pre-set, the turbine torque Q_T becomes negative.

Propeller

The equations used into the control system design are for shaft speeds over a certain value. For lower shaft speeds the advance coefficient J, computed by means of the equation (4) reaches highter values outside the range of tabulation of the coefficients KQ and KT.
To simulate the behaviour of the propeller also for low or null shaft speeds the following equations have been used:

(11) ρ.bre.K'Q.D^3. ((V.bwf)^2+(N.D)^2)   propeller torque
(12) ρ.btd.K'T.D^2. ((V.bwf)^2+(N.D)^2)   propeller thrust

K'Q and K'T are modified coefficients of torque and propeller thrust.
These coefficients are function of the propeller pitch and of the modified advance coefficient J. The relations between the modified coefficient and normal ones are as follows:

(13) $K'Q = \dfrac{KQ}{1+J^2}$; $K'T = \dfrac{KT}{1+J^2}$; $J' = \dfrac{J}{\sqrt{1+J^2}}$

Simulator Description

The simulator has been based on a 16 bit word minicomputer connected to an analog and digital input/output interface to/from the automation plant under test.
The software of the minicomputer consists in a simulation program managed by a real time operative system. The simulation programme is divided into a start modulus also controlling a CRT terminal, in the fast calculation and in the slow calculation moduli.   The start modulus is started up by the operative system at computer power on time.
The start modulus first qualifies the execution of the other moduli, then keeps turning   in loop, controlling the display terminal. Through the CRT terminal it is possible to modify on-line the model parameters and read the values of the simulated variables.
The fast calculations modulus is periodical and is carried out by the operative system every 0.2 seconds. The module obtains input values   from the automation plant (e.g.: the value of the gas turbine throttle or the condition of the friction clutch engagement command), carries out the algorithms relative to the balancing equation of the torque and transmits the results to the automation plant (e.g.: the value of the actual propeller shaft speed).
The slow calculation modulus is similar to the fast calculation modulus but has a periodicity of 0.5 seconds. The slow calculation modulus executes the algorithms of the models whose variables do not vary very quickly and can therefore be calculated with a relatively slower sampling period.
All the programmes are written in Assembler, the mathematical calculations are

carried out with notation in fixed point to get calculation speed higher than that
of a programme with calculations in floating point. The use of the notation in
fixed point has called for the conversion of all the variables in a numerical scale
defined between the limits of -32767 and +32767. The use of the fixed point needs
precautions in the execution of the calculations due to overflow and rounding off
problems.

SIMULATOR FOR A TRAINER

In the following paragraphs details are supplied on a trainer for   CODOG
frigate propulsion control system operators. The trainer is partitioned into two
sections: a propulsion control console (quite the same as that fitted on board) and
a simulator console.
A prospective view of the propulsion plant and of the control system is shown in
Figure 2.
Figure 3 is a photograph of a trainer realized for the Italian Navy.
The trainee actions the controls of the automatic control console according to
the instructor's orders. The simulator reproduces exactly and in real-time the
behaviour of the propulsion machinery and the hull, it is therefore able to stress
the control system (and the trainee) so as to reproduce the on board operation in a
completely realistic manner.
During the training periods the instructor is at the command console of the simula-
tor. He carries out the actions to the trainees as working from the ship's bridge:
in fact the instructor is able to transmit speed and course orders be means of a
couple of telegraphs (the same are fitted on board on the bridge). The instructor is
acknoledged about the machinery through a duplicate of the main indicators fitted on
the control room console. The instructor can read on a CRT terminal the parameters
representing the behaviour of the ship which are not available on the actual ship.
(e.g.: the value of the propeller thrust).
The instructor can influence the functioning of the simulated machinery by modifying,
through the CRT terminal, the functional parameters of the models (such as the ef-
ficiency relating to the machinery, the displacement of the ship, the sea motion).

SEPA 7206 CONTROL STATIONS AND SIGNAL FLOW SCHEMATICS

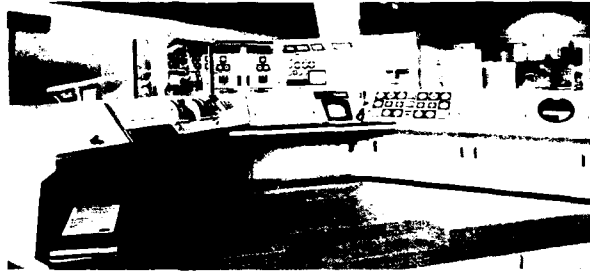Figure 2 - Automation plant and ship's propelling machinery

Figure 3 - Ship propulsion trainer

The instructor can introduce misfunctions on the models either by action on the CRT keyboard or by means of indipendent switches. The introduction of misfunctions is particularly useful, because it allows the operators to recognize the abnormal situation in the propelling machinery through actions and indications given by the control system and to learn how to carry out the appropriate action.

The simulator allows the contemporary simulation of the two ship's shafts functioning assimmetrically and of their reciprocal interactions.

The machinery simulator uses the models developed for the control system testing, integrated with models previously omitted because they did not influence control system action or did it with constant logical conditions. A brief description of the further models added follows.

Model Of The Reduction Gear Lubrication And Cooling System

The model calculates pressure and temperature of the lubricating oil and cooling water of the reduction gear. The pressures are function of the shaft speed and of oil temperature and are enabled according with run/stop condition of electropumps. The temperatures are function of the power transmitted by the reduction gear and of the pressure of the fluids. The functions and the time constants which simulate the dynamics of the system in normal conditions have been obtained from registrations carried out on board on similar systems, in operating conditions. The function concerning anomalous functioning conditions has been extrapolated from those referring to normal conditions.

The instructor, through commands at the simulator, can select a normal or abnormal functioning to train the crew to act in the presence of misfunctioning.

Signals driving indicators or fed into the alarm and monitoring system relating to the cooling and lubrication of the engines, bearings and propeller pitch servo have been calculated in a similar way.

Modifications To The Computation Of The Propeller Torques And The Equation Of The Thrust To Take Into Account The Interaction Between The Shafts

The propeller torque Q_E of each shaft is multiplied by a coefficient normally

unitary, function of the sum of two terms; the first is a periodical term simulating
the sea motion, the second simulates the effect of the rudder and is function of
the product of the ship speed and the rudder angle.
The thrust equation previously described is modified to take into account the influen-
ce of the two propeller shafts as follows:

(14) $T_1 + T_2 - R = M \cdot \dfrac{dV}{dt}$ T_1 right propeller thrust

   T_2 left propeller thrust

Air Starting System Model

   The air starting system consists in a series of compressors, tanks and pressu-
re reductors which supply compressed air for various systems and for the starting
of the diesel and turbine engines. The models calculates the air pressure in the
tanks. The pressure increases according to the actioning of the motor driven compres-
sors and decreases when the engine starter air-valves are opened.

Simulation Of The Sensors And Actuators

   In the training unit the simulator is connected to the automation plant so as
to also simulate the electrical behaviour of the sensors and actuators fitted on
the machinery.
This feature has brought the development of   interface electronics simula-
ting the electrical behaviour of thermoresistors, thermocouples, differential
transformers, potentiometers and servovalve coils.

Trainer Lay-Out

   The trainer system overall lay-out is shown in Figure 4.
The automation plant consists in a propulsion control system and a monitoring sistem.
   The control system is based on two modules including a minicomputer and its
relevant in/out electronics. The two interfaces units(one per shaft)are independent.
   One computer controls both the shafts, the other acts as a back-up to the first.
The "master" computer supplies to the "slave" the results of the elaboration.
If the master computer breaks down, a watchdog feature turns the slave computer into
action. The slave computer, having been continuosly up-dated, is able to keep control
in a smooth and bumpless way as far as control system and propulsion plant are
concerned.
   The monitoring system is based on a computer-based module which manages 200
channels supplied by six data conditioning terminals.

The data conditioning terminals fitted in the engine room, receive signals from the
sensors, normalize the scale, convert them into digital signals and transmit them
through serial lines to the computer module.
This system allows a considerable reduction in the number of connection cables
between the engine room and the control room.
   The simulator consists in three interconnected computer based modules.
Two modules are connected together by the third through a serial line.
The two side modules each simulates the machinery of a shaft of the ship.
The central module simulates the models common to the two shafts such as the hull,
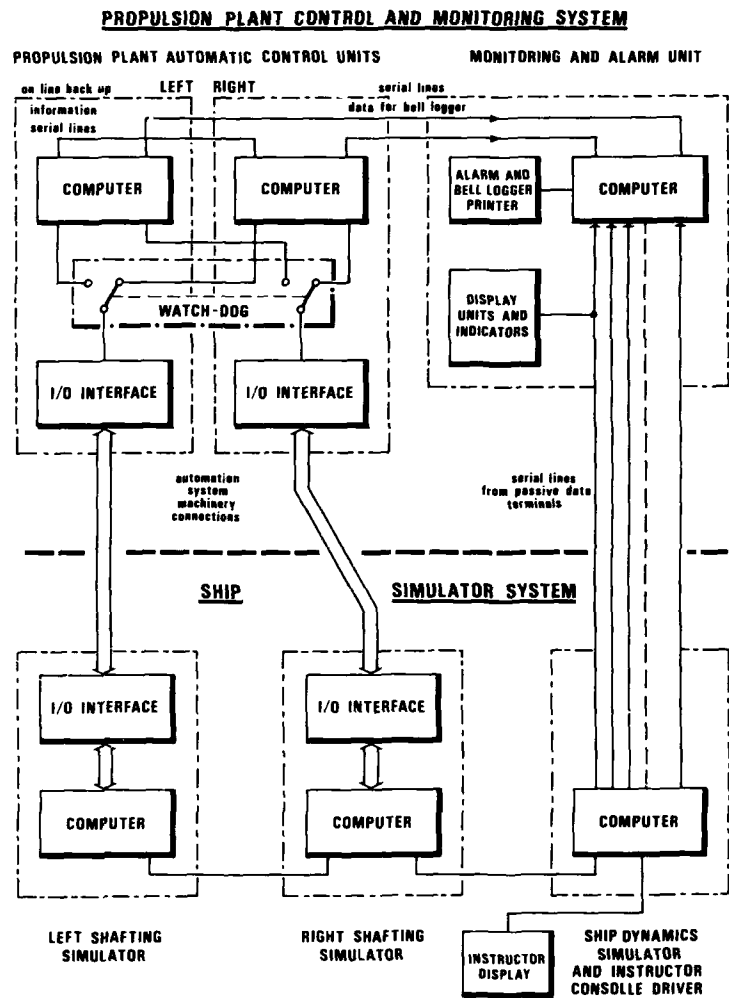the sea motion, and the common auxiliary machinery.

PROPULSION PLANT CONTROL AND MONITORING SYSTEM

PROPULSION PLANT AUTOMATIC CONTROL UNITS   MONITORING AND ALARM UNIT

on line back up   LEFT   RIGHT   serial lines
information   data for bell logger
serial lines

| COMPUTER | COMPUTER | ALARM AND BELL LOGGER PRINTER | COMPUTER |

WATCH-DOG

DISPLAY UNITS AND INDICATORS

| I/O INTERFACE | I/O INTERFACE |

automation system machinery connections

serial lines from passive data terminals

SHIP   SIMULATOR SYSTEM

| I/O INTERFACE | I/O INTERFACE |

| COMPUTER | COMPUTER | COMPUTER |

LEFT SHAFTING   RIGHT SHAFTING   INSTRUCTOR   SHIP DYNAMICS
SIMULATOR   SIMULATOR   DISPLAY   SIMULATOR
                                                                  AND INSTRUCTOR
                                                                  CONSOLLE DRIVER

FIG. 4   TRAINER SYSTEM LAY-OUT

The central module drives the CRT terminal for communication with the instructor; it also emulates the six data conditioning terminals and it is connected with the monitoring system through six serial lines.
The basic structure of the three modules of the automation plant and the three modules of the simulator is the same.
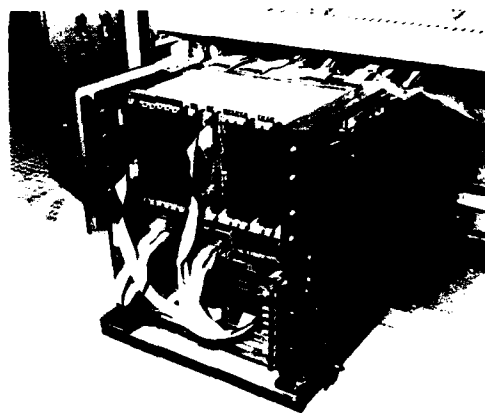One of the modules is shown in Figure 5.

Figure 5 - Interface and Computer Module

the facility were discussed in Ref (1). This paper presents the work to date on achieving those aims by outlining the mechanics of the system produced and discussing the problems encountered.

THE EVALUATION CENTRE

Various possible options were considered for providing the evaluation facility. These ranged from testing against the actual plant on a test bed to the use of different forms of simulation and these are discussed in Ref (1). The use of digital computer based simulations however provides a cost effective and flexible means of meeting the evaluation requirements. Flexible because functions may be added or plant characteristics changed by rewriting software.

The Evaluation Centre currently incorporates six mini computers which simulate a COGAG propulsion system. The computers are configured as shown in Fig 1 with four mini computers containing simulations of the major items of plant, gas turbines, gearbox, and controllable pitch propeller, with a fifth representing the propeller load and hull resistance. These five minis are connected via 16 bit parallel data links to a central master computer which controls the running of the individual simulations, co-ordinates communication between them and simulates the interaction between the various propulsion elements by solving the system level equations. This master computer also acts as a central data collection point and provides a number of operator facilities for data display and storage.

A number of different options were considered when deciding how the simulations and their computers should be configured and these are discussed in Ref(2). The chosen configuration has the following advantages:

    i. Each simulation is contained within an individual computer; it is the requirements of each individual simulation that dictate the size and power of each computer; if the requirements of a particular simulation change and the chosen processor is too small then that processor can be upgraded without affecting the rest of the system.

    ii. If additional plants are considered necessary these can be simulated in a separate computer and linked into the master via an additional parallel link.

    iii. The central computer acts as a control station controlling and synchronizing the operation of the simulation computers.

    iv. By selecting a fairly large and powerful mini for the central computer a range of operator facilities can be supplied including data collection and display.

Each mini has associated with it a number of interface devices which allow the simulation to communicate with the master computer and with its respective control unit. The control unit interfaces convert the simulation generated signals into a form that the controllers would normally expect to receive via plant mounted transducers, and conditions the controller output signals to suitable levels for use by the simulation computers.

Real time operation of the simulations, essential for testing prototype control equipment, is governed by a master clock within the central computer. At the beginning of each time step the central computer issues a directive to start the operation of the individual simulations. On receipt of this directive each simulation updates the control system interfaces with data calculated during the previous time step, reads in demands issued by the controller and then executes its simulation. On completion data is transmitted to the master computer and the
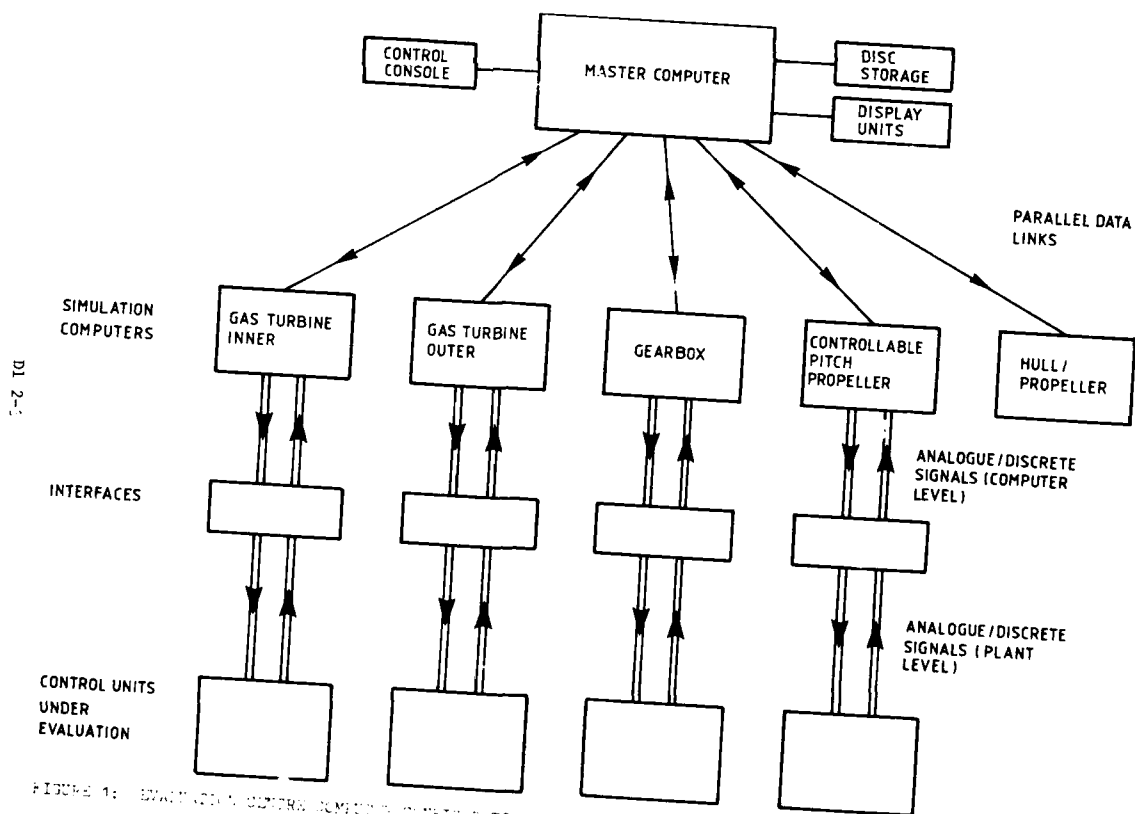
FIGURE 1: EVALUATION & CONTROL COMPUTER CONFIGURATION

simulation computer lies dormant for a period of time.

Once all the simulations have completed the communication to the master computer, the system level equations are then calculated and the results sent to the simulations for use during the next time step. All these activities have to be completed inside the system time step or real time operation cannot be maintained. Fig 2 shows the series of events and timing of these various activities for the propulsion system.

THE PROPULSION SYSTEM

The facility is being applied, initially, to the evaluation of a digital control system for a warship propulsion plant. The propulsion plant, for which the control system has been designed, is a COGAG configuration and, because it has been designed without a specific ship in mind, has been termed the Reference System. As shown in Fig 3, two Rolls-Royce SM1A gas turbines drive into a combining gearbox which contains primary and secondary gearing, self selecting clutches on each intermediate shaft, a disc brake attached to the output half of one of the intermediate shafts and a slow speed shaft turning motor. The controllable pitch propeller system is based on the Stone Manganese Marine Engineering Ltd open circuit hydraulic system. In order to provide a representative load for the system nominal ship resistance and propeller torque/thrust characteristics have been defined for a ship of 5000 tonnes displacement.

SIMULATIONS

The requirements of the simulations can be considered on two levels. At the system level they provide a dynamic simulation of the complete propulsion system. At this level, consideration of the system dynamics determines the overall system time step and dictates the minimum number of inter simulation parameters required to model the complete system.

On the second level the individual plant simulations are required to respond to all the demands issued by the control units and to supply all the signals normally transduced on the real plant. These simulations have to be fully dynamic and have to be capable of representing the plant in all its possible operating states, namely from being dead with everything switched off to running in excess of full power. At this level the number of functions required by the control unit, together with the complexity of the plant, determines the complexity and hence size of the simulation. If the plant dynamics cannot be accurately modelled using the overall system time step then the individual simulation time-steps have to be set to appropriate factors of the system time step.

In the case of the propulsion system simulation the overall time step was set at 120 milli-seconds while the gas turbine and controllable pitch propeller run with 40 ms time steps.

GAS TURBINE

As can be seen in Fig 4, in terms of the propulsion system the gas turbine simulations are required to convert input fuel flow into torque developed by the power turbines. In terms of the control unit requirements they have to respond to some 12 discrete inputs and supply 16 state indications with 50 analogue outputs. Of these analogue outputs six are used as feedback signals for a continuous analogue controller, as described in Ref 3, for controlling LP spool speed and for ensuring that the engine does not enter any undesirable operating regimes, the remainder are used for surveillance purposes.
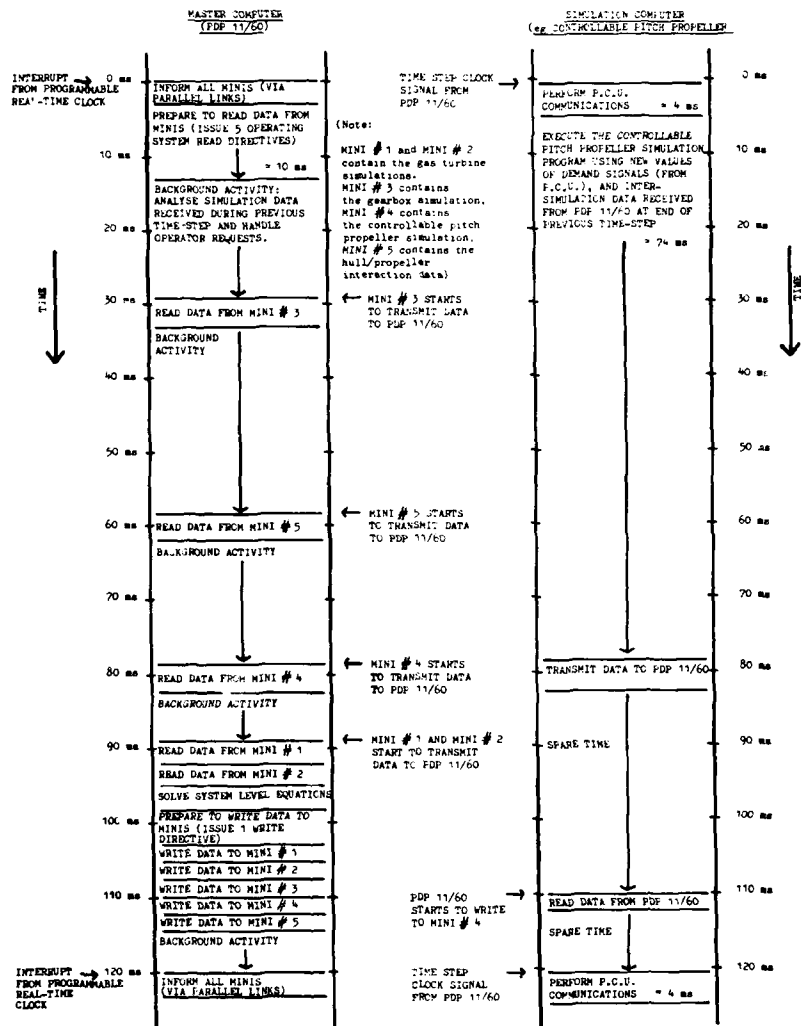
MASTER COMPUTER
(PDP 11/60)

SIMULATION COMPUTER
(eg CONTROLLABLE PITCH PROPELLER)

INTERRUPT → 0 ms
FROM PROGRAMMABLE
REAL-TIME CLOCK

INFORM ALL MINIS (VIA PARALLEL LINKS)

PREPARE TO READ DATA FROM MINIS (ISSUE 5 OPERATING SYSTEM READ DIRECTIVES)

≥ 10 ms

BACKGROUND ACTIVITY: ANALYSE SIMULATION DATA RECEIVED DURING PREVIOUS TIME-STEP AND HANDLE OPERATOR REQUESTS.

READ DATA FROM MINI # 3

BACKGROUND ACTIVITY

READ DATA FROM MINI # 5

BACKGROUND ACTIVITY

READ DATA FROM MINI # 4

BACKGROUND ACTIVITY

READ DATA FROM MINI # 1

READ DATA FROM MINI # 2

SOLVE SYSTEM LEVEL EQUATIONS

PREPARE TO WRITE DATA TO MINIS (ISSUE 1 WRITE DIRECTIVE)

WRITE DATA TO MINI # 1

WRITE DATA TO MINI # 2

WRITE DATA TO MINI # 3

WRITE DATA TO MINI # 4

WRITE DATA TO MINI # 5

BACKGROUND ACTIVITY

INTERRUPT → 120 ms
FROM PROGRAMMABLE
REAL-TIME CLOCK

INFORM ALL MINIS (VIA PARALLEL LINKS)

TIME

0 ms
10 ms
20 ms
30 ms
40 ms
50 ms
60 ms
70 ms
80 ms
90 ms
100 ms
110 ms
120 ms

TIME STEP CLOCK SIGNAL FROM PDP 11/60

(Note:

MINI # 1 and MINI # 2 contain the gas turbine simulations.
MINI # 3 contains the gearbox simulation.
MINI # 4 contains the controllable pitch propeller simulation.
MINI # 5 contains the hull/propeller interaction data)

← MINI # 3 STARTS TO TRANSMIT DATA TO PDP 11/60

← MINI # 5 STARTS TO TRANSMIT DATA TO PDP 11/60

← MINI # 4 STARTS TO TRANSMIT DATA TO PDP 11/60

← MINI # 1 AND MINI # 2 START TO TRANSMIT DATA TO PDP 11/60

PDP 11/60 STARTS TO WRITE TO MINI # 4

TIME STEP CLOCK SIGNAL FROM PDP 11/60

PERFORM P.C.U. COMMUNICATIONS ≈ 4 ms

EXECUTE THE CONTROLLABLE PITCH PROPELLER SIMULATION PROGRAM USING NEW VALUES OF DEMAND SIGNALS (FROM P.C.U.), AND INTER-SIMULATION DATA RECEIVED FROM PDP 11/60 AT END OF PREVIOUS TIME-STEP

≥ 74 ms

TRANSMIT DATA TO PDP 11/60

SPARE TIME

READ DATA FROM PDP 11/60

SPARE TIME

PERFORM P.C.U. COMMUNICATIONS ≈ 4 ms

TIME

0 ms
10 ms
20 ms
30 ms
40 ms
50 ms
60 ms
70 ms
80 ms
90 ms
100 ms
110 ms
120 ms

FIGURE 2: SEQUENCE OF EVENTS AND RELATIVE TIMING IN THE PROPULSION SYSTEM SIMULATION.

D1 2-5

INNER GAS TURBINE

GEAR BOX

SHAFT BRAKE

CONTROLLABLE PITCH PROPELLER

OIL TRANSFER BOX

CLUTCHES

OUTER GAS TURBINE

TURNING MOTOR

FIGURE 3: REFERENCE PROPULSION SYSTEM.

FIGURE 4: SYSTEM LEVEL INTERSIMULATION PARAMETERS

Dl 2-7

The simulation models both the gas generator and the power turbine characteristics, also the on-engine fuel controls, as shown in Fig 5, and includes ancillary functions for producing lub oil pressures and temperatures etc.

For the purposes of producing the simulation the engine operating range was considered to consist of two stages, dead to idle and idle to full power. The region from dead to idle has been modelled using look up scenarios which output parameters during the start up and shut down phases as a function of time and in response to the control system demands. A transfer function type approach has been adopted to model the region between idle and full power. The simulation is based on a form developed by Rolls-Royce and uses a combination of measured data and derived functions to predict the steady state and transient operation of the engine. A block diagram of the model structure is shown in Fig 6. The advantages of this form of model are that it is extremely straightforward to implement, requires very little computing time and power, and can be updated by simply replacing data tables. The disadvantages are that only a limited number of parameters are actually developed as part of the modelling process but for control systems evaluation purposes, the model can be structured so as to produce those required.

In order to model the gas turbine dynamics accurately, and ensure stable operation when run in conjunction with the closed loop controller, the simulation time step had to be reduced to 40 ms. This means that the gas turbine simulation has to complete three cycles and communicate to the control unit three times during the 120 ms system time step; communication to the central computer still only occurs every 120 ms.

GEARBOX

In order to maintain synchronous operation of the complete system the functions of the gearbox have to be split such that the gearbox simulation only determines the system configuration, by determining the clutch states, while the torque balance system level calculations are performed in the central master computer.

Inputs to the system level equations are the two power turbine torques and the propeller shaft torque together with the gearbox clutch states. The shaft equations combine these torques according to the engine/clutch configuration and, allowing for losses, produce new estimates of shaft acceleration and hence speeds. These updated shaft speeds are returned to their respective simulations for use during the next time step. The gearbox simulation itself contains mathematical representations of the self-selecting clutches, shaft brake and turning motor.

The clutches are of the SSS Ltd non baulking type and the simulation models the action of ratchet and pawl mechanisms, the sliding member and the controlling dashpot, during engagement and disengagement. Lock in and lock out devices are also included and the simulation responds in the appropriate manner to requests for their operation.

The shaft brake is an air-operated disc unit mounted on the output half of one of the intermediate shafts. The simulation models the torque characteristics of the brake unit as a function of:-

i. the number of pads

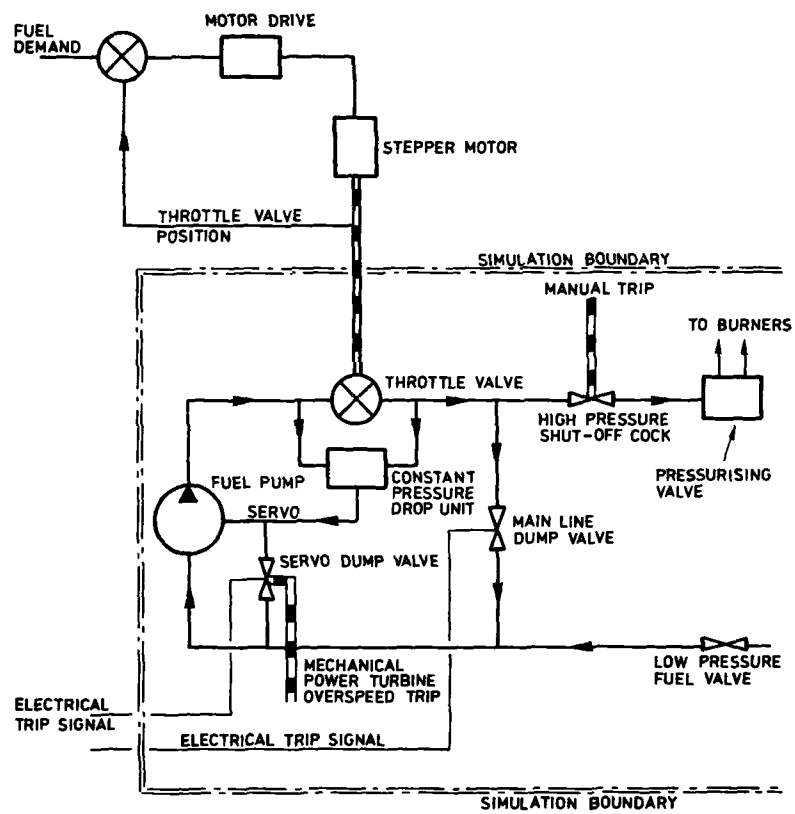ii. the brake air pressure

iii. brake friction coefficient

D1 2-8

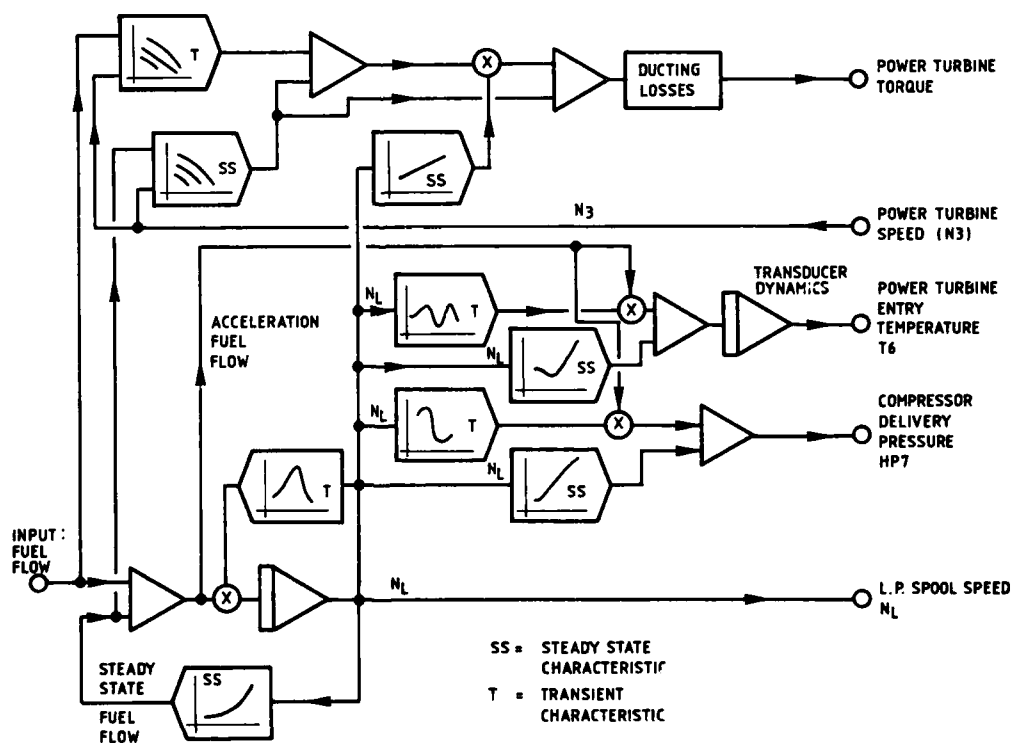FIGURE 5 : GAS TURBINE FUEL CONTROL SYSTEM.

FIGURE 6: GAS TURBINE SIMULATION : TRANSFER FUNCTION MODEL BLOCK DIAGRAM.

The friction coefficient varies as a function of temperature and the simulation takes account of these effects by calculating both surface and bulk temperatures which vary as a function of time and power absorbed.

CONTROLLABLE PITCH PROPELLER (PITCH CONTROL SYSTEM)

The controllable pitch propeller ~~simulation is based upon the characteristics of the Stone Manganese Marine Engineering, Ltd open circuit hydraulic system. The system is designed around an open centre spool valve which is used to control the flow of hydraulic oil to a servo motor mounted in the propeller hub. Displacement of the servo motor varies the applied pitch angle. The system uses three fixed displacement screw pumps, two being electrically motor driven and one geared to the propeller shaft; these pumps may be used in any combination. A block schematic of the system is shown in Fig 7, from which it may be seen that the system consists of two closed loop servos connected in series. The first is an electronic actuator which converts the electrical pitch demand signal into mechanical displacement of the input rack. The second is a hydro mechanical system containing the spool valve and the hub servo motor with feedback in the form of mechanical displacements transmitted from the hub servo motor via the oil transfer tubes passing through the centre of the propeller shaft.

A functional element diagram of the CPP simulation is shown in Fig 8. The spool valve has been modelled using a measured pressure/displacement characteristic which is modified by the flow rates occurring in the system, ie by the pump output flow rates and the flow to and from the hub. The hydraulic load placed on the system is a function of both the propeller spindle torque, which is supplied by the hull/propeller simulation, and the various friction components present in the system.

In order to obtain stable operation of the simulation the time step has been reduced to 40 milliseconds. The simulation is required to complete three cycles per system time step however, communication to the control unit and to the master computer still only occur once every system time step.

HULL/PROPELLER

The load on the system is modelled in the hull/propeller simulation. This consists of a number of look up tables which define the propeller torque and thrust characteristics in the form of the modified torque and thrust coefficients, K_Q' and K_T' as functions of the propeller speed of advance J' for various angles of applied pitch. The simulation also contains data relating to the hull resistance characteristics and to the spindle torque characteristics for use in calculating the load experienced by the controllable pitch propeller.

A second order interpolation routine is used to provide estimates of shaft torque, thrust, propeller spindle torque and ship's speed based on values of shaft speed, pitch angle and previous ship's speed.

ELECTRONIC INTERFACES

Signals that pass between the control units and the plant can be considered to be one of four different types:-

1. discrete level outputs, commands to open valves, switch motors on etc.

2. discrete level inputs, status information as to whether a valve is open or closed, whether a motor is running or stopped.

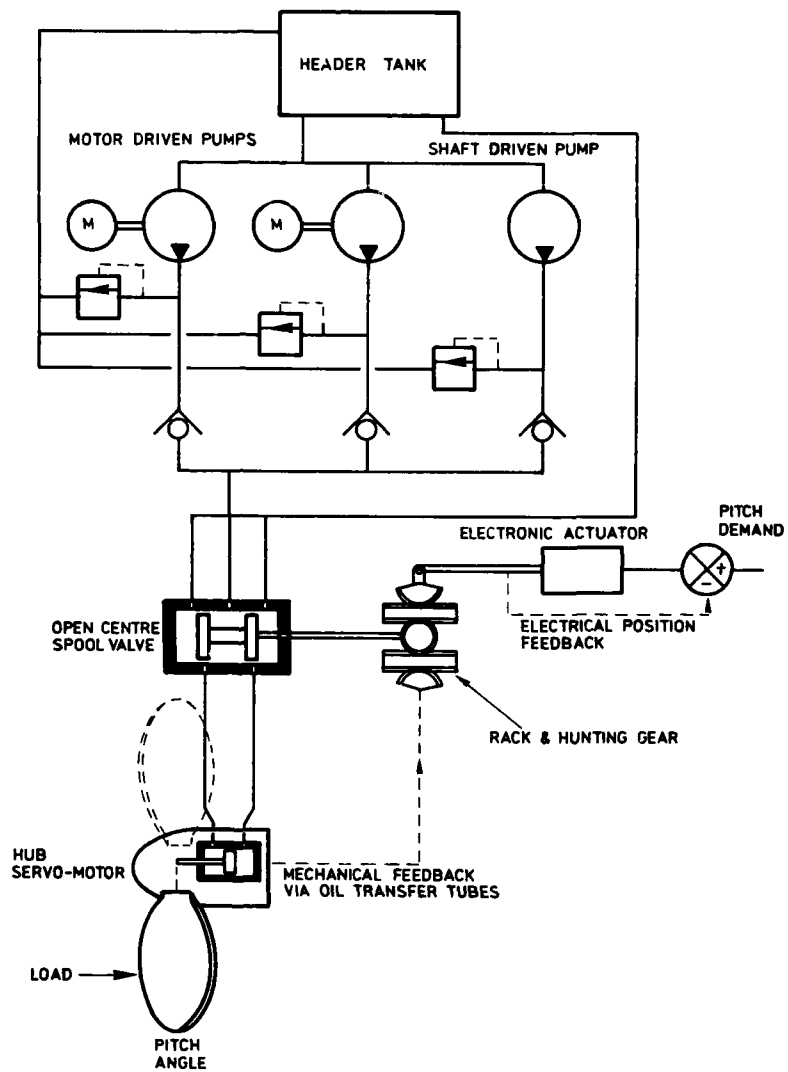3. continuous analogue outputs, control demands for fuel flow or pitch demand.

HEADER TANK

MOTOR DRIVEN PUMPS

SHAFT DRIVEN PUMP

M

M

OPEN CENTRE
SPOOL VALVE

ELECTRONIC ACTUATOR

PITCH
DEMAND

ELECTRICAL POSITION
FEEDBACK

RACK & HUNTING GEAR

HUB
SERVO-MOTOR

MECHANICAL FEEDBACK
VIA OIL TRANSFER TUBES

LOAD

PITCH
ANGLE

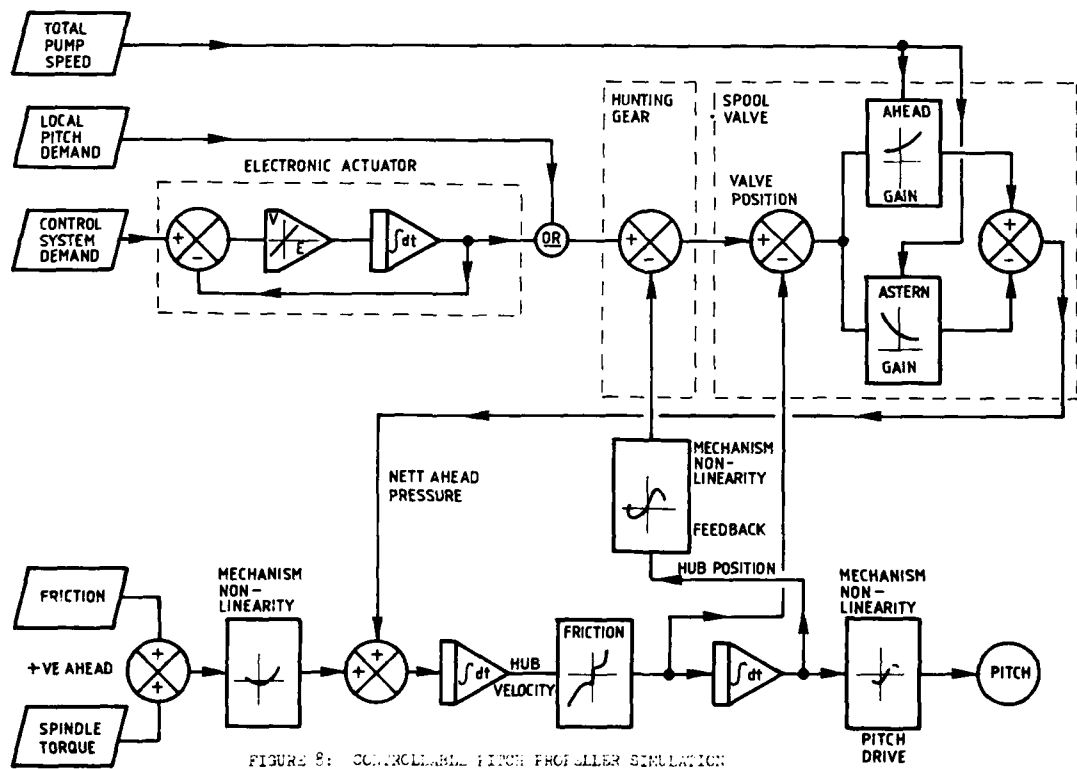FIGURE 7: SCHEMATIC OF CONTROLLABLE PITCH PROPELLER SYSTEM.
D1 2-12

FIGURE 8: CONTROLLABLE PITCH PROPELLER SIMULATION
FUNCTIONAL ELEMENT DIAGRAM

D1 2-13

4. continuous analogue inputs, voltage signals from pressure gauge transducers of thermocouples, frequency signals from speed probes etc.

In order for the simulations to respond to, and supply all the signals that would normally pass between the control units and the plant, a considerable amount of interface electronics has been developed to convert the control signals into a form that are mutually acceptable to both control unit and simulation computer.

Each of the five mini computers containing the plant simulations is housed in a separate cabinet. Four of these are similar to that shown in Fig 9 while the fifth, the hull/propeller simulation, does not have to communicate with a control unit and therefore does not require the signal convertion equipment. The interfaces for each simulation are shown in Fig 10 with the hardware being identical between the cabinets.

With respect to the simulation the discrete input signals are at 24 V levels, these are conditioned and fed via optical isolators to standard computer interface cards at TTL levels. The discrete output signals, initially at TTL levels, are again optically isolated and used to drive relays to present no-volt contacts for use by the control unit. Provision has been made for up to 16 discrete input and 16 discrete output channels.

Analogue inputs to the simulation are accepted through analogue isolation amplifiers and conditioned to be between 0 and 5 V. These signals are then digitised via a 10 bit A/D converter; up to four channels of analogue input are available.

Each analogue signal to the control unit is supplied by an individual conditioning amplifier housed in the simulation cabinet. These conditioning amplifiers have output characteristics that simulate the specific transducer characteristics normally used to measure the parameter value on the plant. In all, four different types of amplifier were required to simulate:

a. thermocouples, millivolt outputs.

b. resistance temperature bulbs, outputs equivalent to resistance change.

c. pressure transducers, voltage output.

d. magnetic reluctance speed probes, frequency output.

Up to sixty control system inputs can be accommodated but because of restrictions on the number of D/A converters available only sixteen independent parameters can be output from the simulation at any one time. To overcome this limitation a pin board matrix has been used whereby any number or combination of the output amplifiers may be driven from any one of the sixteen input channels. For example, in the case of the gas turbine, the control unit expects to receive some twelve values of power turbine, entry temperature (T6). As the simulation only produces one estimate of this value, the pin board is used to parallel the twelve output amplifiers supplying the T6 values to the control unit, from the single drive channel being supplied by the simulation.

Identical hardware is used within each simulation cabinet and the cabinets only become specific by way of the simulation software and pin arrangement on the matrix board together with the combination of output amplifiers.

These interfaces also contain test mode switches which allow each signal passing between the simulations and the control units to be interrupted and test signals to be injected. In this manner the simulations and, if necessary, the control units can be tested independently of each other.

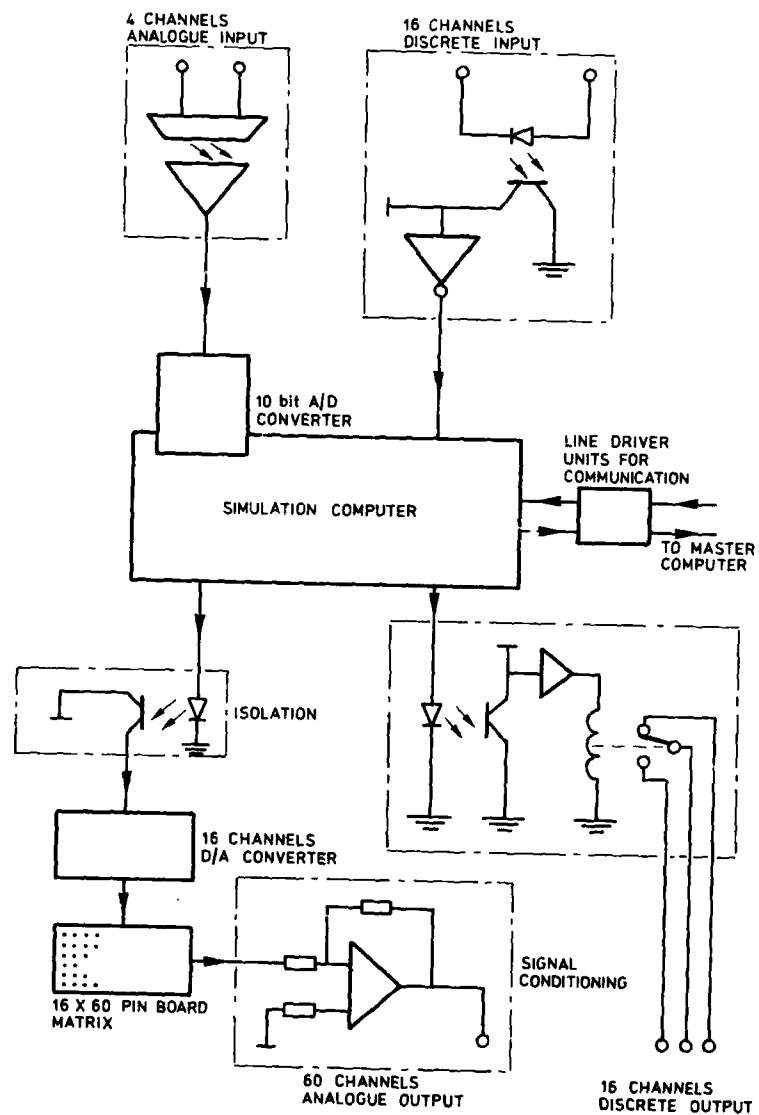D1 2-14

FIGURE 9: SIMULATION CABINET.

FIGURE 10: SCHEMATIC OF SIMULATION ELECTRONIC INTERFACES.
D1 2-16

SYSTEM OPERATION

Control of the simulation facility is effected from a master console connected to the central computer. From this console the simulations can be run and control is exercised as to which parameters are sent from the simulations to the master computer for display and recording.

A minimum number of parameters are always sent to the master computer, these represent those required by the system level equations, but any parameter that is calculated within any of the simulations is available to be sent to the master if required. The parameters of interest will vary depending upon the particular trial being performed and have to be requested either at the beginning, or during a trial.

Parameters that are sent to the master are available for either:

1. display of current value on a VDU.

2. recording on an analogue pen recorder,

3. recording on disc for subsequent off-line data analysis.

At any one time up to seven parameters may be displayed on the VDU with eight more on the pen recorder and a further thirty being sent to disc. The off-line data analysis is performed on another mini computer which has extensive data analysis routines for manipulating, displaying and producing hard copy output of the data. The simulation data is read off disc in the master computer and transferred for analysis via a serial data link.

EVALUATION CENTRE USES

At present the first of the prototype propulsion control system units are being installed in the Evaluation Centre. In the first instance the Centre will be used simply as a means of checking that the units do perform their required functions. This will lead on to an evaluation of the control philosophies adopted and to studies into the effectiveness with which these philosophies have been implemented in both hardware and software terms.

Future uses of the Centre will include:-

1. Failure effect studies; with facilities to enable the introduction of machinery faults and failures into the plant simulations and the opportunity to 'manufacture' faults in the control units the Centre is ideally suited to augment failure mode and criticality analysis which tend in general to be paper studies only.

2. Ergonomic studies concerning the effectiveness of the ship operator interfaces for both data display and control positions.

3. With the experience gained from use of the control systems at the Centre ship operating procedures will be developed. These will cover all forms of plant operation from remote system level control through the reversionary control options and down to local plant level control.

4. The development of fault finding and diagnostic procedures; as in 1 above the ability to easily introduce faults into the system will be exploited in the development of fault identification techniques for ship operator/ maintainer use.

5. Once the control systems are in service then the facility provides a means of investigating in-service faults and evaluating any possible equipment, plant or control system, modification prior to ship implementation.

In general the Evaluation Centre is capable of investigating the majority of areas concerning the man/control system/plant interactions. The Centre is not laid out like a ship and is not intended to consider environmental conditions either in terms of operator's comfort or in terms of electrical interference being induced in the control equipment.

DISCUSSION

With the facility now operational and with the benefit of hindsight it is possible to pick out the good and bad points of the approach adopted. In general the philosophies set out in Ref (1) three years ago have been adhered to with only minor modifications being introduced to produce a more useful facility.

The concept of the individual simulation computers connected to a central master has worked well. With this arrangement additional machinery items can be simulated, as the need arises, by attaching additional mini computers to the master, the limiting factor to this arrangement being the capacity of the master computer. By using a fairly large mini as the master, extensive data recording and display facilities have been possible.

The other main advantage concerns the size, power and capacity of the simulation computers themselves. The computing requirements of the individual simulation computers are determined by the simulations themselves and if a simulation expands beyond the capacity of its computer then that particular mini computer can be upgraded without detriment to the rest of the system and at relatively low cost. If all the simulations were contained in one large computer and the simulation requirements outgrew its capacity then it is obviously very expensive to replace a large, powerful, probably main frame computer. One major lesson learnt during this project was that the requirements of the simulations always grew and never reduce. Fortunately the simulation computers that were purchased had a capacity in excess of the original estimates.

It was intended to use parametric models for all the simulations, namely models that define the plant performance in terms of physical characteristics and properties. Wherever possible this objective has been maintained, however in some cases this has not been possible due either to lack of data or timing considerations in order to maintain real time operation. The most notable deviation was in the case of the gas turbine simulation. This simulation was originally of the lumped parameter type described by Saravanamutto and Fauke, Ref (4) but due to a lack of data defining the various gas generator component performance characteristics over the wide range of operation required, idle to full power, it became necessary to use a very much simpler transfer function type model. This form of model is strictly only valid in the steady state, with the engine operating on its running line and for the small deviations about this line that occur during normal transient manoeuvres; care will need to be employed in the interpretation of the results obtained during failure effect studies which cause the gas turbine simulation to deviate wildly from the operating line.

All the simulations are modular in structure with each module relating to a physical, or conceptual, item of the plant. This arrangement has the advantage that the characteristics of specific items can be changed with ease. In some cases the simulations were developed in advance of the plant being built and it is intended to update the performance characteristics when more reliable data becomes available.

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SIMULATION AS A TOOL IN WARSHIP CONTROL SYSTEM
DESIGN AND DEVELOPMENT

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ABSTRACT

Simulation has now been used for many years as a basic tool in the design
of warship propulsion control systems. This paper reviews recent experiences
in the growth of importance of simulation in this field, including those brought
about by the recent changes in digital control technology.

INTRODUCTION

Simulation of ship and propulsion systems has wide applications in ship
design. It is used from initial feasibility design studies, through progressive
design stages to final sea trials and beyond, the models growing in scope and
complexity as more detailed design aspects are investigated. Typical areas to
which simulation is now being applied include:
- ship performance evaluation;
- propulsion plant performance evaluation;
- propulsion plant selection and development;
- control system functional design.
- control system development;
- control system setting to work.

The primary advantage of using simulation models of ship and propulsion
plant lies in giving design teams a powerful tool for the prediction of steady state
and transient performance of the whole system, including dynamic interactions.
Simulation accuracy is only as good as the data available and the assumptions
made, but, nevertheless, it does allow the designers to make the best use of
available data to make decisions early in the ship design phase.

The advent of digital technology for warship control system implementation
has placed an even greater emphasis on the early definition of the functional
requirements of the control system, to allow for the greater lead times required
in debugging and shore testing of digital systems. In addition to the use of
simulation models for control system functional definition, the simulation model,
operating in real time, provides a relatively inexpensive "test bench" for control
system development and testing.

SIMULATION MODELS

A ship simulation model generally consists of the organisation of a number
of program modules, each module representing a major component of the system,

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such as hull, propeller, prime movers, shafting, gearing (with associated
clutches and couplings etc.) and the control system. Program modules have been
developed, in close association with plant manufacturers and research establish-
ments, for a wide range of equipments including:
- gas turbines : industrial and aero derivative;
- steam turbines and associated plant;
- diesel engines : low, medium and high speed types;
- gearboxes, clutches, fluid coupling and convertors;
- electrical transmissions : dc and ac;
- propellers : fixed and controllable pitch.
The models, where possible, have been validated and refined using model and
full scale plant trials data of steady state and transient performance.

       In general, the program modules are initially of the theoretically based,
parameter type model developed from first principles. The use of suitable trials
data may allow a simplification of this type of model to a transfer function type
which, while retaining the essential model characteristics, generally requires
reduced computational time and capacity. In propulsion control system studies it
has been found that because of the sheer size and computation times required
program modules using both types are necessary, but with the use of transfer
functions being encouraged to simplify the overall model. As usual, choices are
rarely that simple and compromises are made using judgements consistent with
requirements of the study.

       A major task, prior to the start of an investigation, is to determine the
simulation basis data for the particular application and its validity. Initially
the data can only be validated at the model formulation stage by vetting these in
the light of previous experience. However, data for the prime mover models
are based on shore tests of the actual items of plant and a fair degree of con-
fidence can be applied to the transfer function type of models derived from these
data.

       Propeller characteristics for new designs are usually only available from
physical model tank tests and apply, essentially, to steady state conditions.
These become suspect under full-scale and/or transient conditions and provide
some limitation, as is well known, on their validity for manoeuvring simulation.
However, comprehensive studies, both model and full scale, have been under-
taken to give a deeper understanding of the influences of scale, transient be-
haviour, cavitation etc.

       These studies have not reached their conclusion, but already some of the
results can be applied to identify where simulation results are likely to be
accurate and where care is needed in their interpretation. It has been found that
steady state operation is accurately predicted, that, during manoeuvring, shaft
speed tends to be reasonably accurate but that torque and particularily thrust
tend to be overestimated. When examining propeller behaviour, the influence of
cavitation should be included in the simulation wherever possible.

       It is vital that the designer should be fully aware of the importance of
model validation and that he should consider measurement and recording of full
scale trials results an essential part of a complete study. To this end it is found
necessary to maintain a team of trials personnel and equipment solely for the

purpose of data acquisition from shore, offshore and sea trials. In addition a comprehensive suite of data analysis programs are used to provide a quantitative comparison of simulated and trials results. Typical results of such a comparison for a COGOG ship during a crash stop transient manoeuvre are shown in Figures 1 and 2.

A collection of appropriate program modules can be organized into a simulation program using either analogue, digital or hybrid computer techniques in continuous or discrete simulations. The choice depends upon the nature of the study, the complexity of the plant and system being modelled, the data available and the presentation of results. In ship propulsion control system studies, real time operation is frequently required, e.g. when an operator and/or control system hardware is employed in the simulation loop. In addition, the increased complexity, sophistication and refinement of program modules now usually means that a continuous hybrid computer simulation model is the only solution.

For a typical naval ship study the hybrid models are now sufficiently comprehensive and sophisticated to allow, without changes to the model structure, examination of ship performance, machinery behaviour and control system requirements, when operating under the following conditions:
- steady state operation, twin or single shaft, differential pitch loadings;
- high power manoeuvring;
- harbour manoeuvring;
- drive mode changeover;
- engine load sharing;
- control system failure mode and effects.
- cyclic propeller loading, cavitation effects;
- propeller shaft stall avoidance;
- clutch/coupling duties;
- specific prime mover loading conditions.

The simulation modules and techniques described above have been developed from experience of a wide range of propulsion system arrangements for both Royal Navy and foreign ships.

APPLICATIONS OF SIMULATION MODELS

Performance Evaluation of Propulsion Machinery

The complete simulation model is built up of modules containing the mathematical models for each major item of propulsion plant, the propulsion control system and the ship. The performance of each module can be evaluated either individually or as part of the integrated model. Proposed propulsion machinery packages can thus be evaluated to establish whether the performance is within the bounds of the required propulsion system operational envelopes for each drive mode.

Machinery Selection and Development

As computer capacity and speeds increase, so could the complexity of simulation models. This increase in complexity not only allows more accurate and representative models of major items of propulsion plant to be produced,

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but also provides information for the specification and selection of machinery components and their auxiliaries. Typical examples are found in the dynamic simulation of the following components:

(a)   drive friction clutches and epicyclic gearbox brakes, to estimate their dynamic duties during a range of drive mode changeovers and starting from rest thus selecting the size of clutch or brake and developing the control modes and settings;

(b)   shaft and transient brakes, to estimate their dynamic duties to determine their sizes, cooling and their limits of application;

(c)   fluid couplings, to estimate the dynamic cooling oil supply duties during a range of dynamic manoeuvres thus sizing the cooling oil supply system and determining the control system requirements to maintain the coupling temperatures within design limits.

Control System Design

The almost universal objective of all ship propulsion control systems is to achieve a good and consistent ship manoeuvring capability without overstressing the propulsion plant. The strategy selected to achieve this objective is a major area of the control system design, irrespective of the technology of implementation. The control strategy is generally determined for the propulsion plant operating in its normal regime, e.g. open sea sprint and cruise manoeuvres. However, the whole operational profile of the ship must be investigated and the propulsion control strategy determined to suit. For example, a particular ship may be required to:

(a)   operate for prolonged periods at low speeds in weather conditions which could have adverse effects on a diesel engine;

(b)   operate quietly at certain propeller speeds;

(c)   avoid operation at a critical propeller speed;

Previously the control strategy and development would have been conducted without knowing how the propulsion system as a whole behaved and the control system would have been proved only during sea trials. Using simulation methods these tasks can be conducted in the ship design stages thus, also, providing an early warning of propulsion and control system problem areas.

The introduction of gas turbine and high speed diesel engines to the marine propulsion world posed new control problems. With simulation models providing a better insight into how the whole propulsion system behaves, these diff'culties have been largely overcome.

Gas Turbine Control System Design

Early gas turbine propulsion systems tended to adopt rather complex control strategies including closed loop control of shaft speed, propeller pitch rate and, in some current designs, even closed loop control of torque. However, there exist regimes where some of these functions acted to the detriment of the propulsion system, e.g.

-     closed loop control of shaft speed could produce transmission overtorques during high speed turning manoeuvres;

-     closed loop control of pitch rate resulted in the fastest rates being applied at low engine powers which could result in shaft underspeeds.

Although there have been vast improvements in the measurement of torque, it is

not yet considered accurate enough to use as a controlling variable.

Experience has proved that good ship performance could be achieved, and the control system reliability could be improved, by pursuing a policy of careful control simplification. Gas turbine drive system control functions which have proved to offer good ship performance are:
- open loop, rate limited, control of gas turbine power demand;
- open loop, rate limited, control of propeller pitch demand;
- the anticipation of pitch reversal, by a fixed pitch angle, so that low shaft speeds are avoided by the early re-application of engine power during ship manoeuvres;
- power limit during a mismatch of propeller pitches for combining gearbox applications.

Diesel Engine Control System Design

The power to weight and volume advantages of industrial, high speed and turbo-charged diesel engines were readily recognised when they were applied in the marine propulsion field. However, the transition phase brought to light some control problems not previously appreciated. The major problem, especially in CODOG applications, was to achieve satisfactory load control where high governor gains resulted in large fuel rack movements for small engine speed changes, and there was a relatively small margin between the propeller load line and the turbo-charger surge line.

Simulation of complete diesel engine propulsion systems driving via controllable pitch propellers showed that, with the introduction of additional fuel rack/engine speed load control functions to:
- reduce demanded pitch rate;
- hold pitch demand;
- pay off pitch demand;
stable acceleration and pitch reversal manoeuvres could be achieved while maximising the available drive torque.

Control System Optimisation

Control functions, like those described above, are used in the propulsion system simulation model to form a control system basis. From this basis, a controls parametric sensitivity analysis is conducted to optimise the control system settings for the particular ship and propulsion system design. This analysis is conducted by studying the effect, on ship and propulsion system variables, of each control system parameter over its full range of settings for a series of simulated transient manoeuvres. An example of the effect of one such parameter is shown in Figure 3 where the range of simulated propeller speeds and thrusts, obtained by varying demanded pitch stroking rate settings, are traced for a typical CODOG, CPP frigate.

The results of this parametric study are used to derive the initial optimum control system settings which, based on the best available data, are recommended to achieve the major objective of a "good and consistent ship manoeuvring capability without overstressing the propulsion plant".

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Failure Analysis

An integral part of control system development is to conduct reliability assurance studies to estimate the reliability of a proposed control system and identify its critical failures. One standard practice for this work is to adopt the procedures contained in MIL STD 1629A to conduct failure mode and effect analyses. However, a difficulty in these analyses, when applied to dynamic systems, is to quantify the effect of failures, especially if they occur during transient manoeuvres. In these cases an ideal solution is to employ the simulation model where the effects of failures, single or multiple, can be quantified economically and safely. A typical example of the output of one such study is shown in Figure 5, where the potentially damaging effects of one gas turbine, high pressure, shut-off cock (HPSOC) failure during a simulated crash stop manoeuvre for a CODOG frigate, is seen causing significant CPP shaft reversal.

CONCLUSIONS

One of the most important lessons learnt in this work over the last ten years is that propulsion control systems should be kept as simple as possible, thus minimising running maintenance and increasing system reliability. This aim is stressed as the growth of digital system capacity makes the temptation to utilise that increased power with more and more complex controls, harder to resist.

The role of simulation models in control system design and development is assuming more importance with the growth of digital systems. Now, more than ever, the economic arguments for employing real time simulation models for control system development and setting to work as well as in the functional design stages are valid, and it is foreseen they will continue to be so.

As the uses of simulation models increase so the need for continual data update and validation increases. To this end the feedback of ship and propulsion plant trials results is essential.
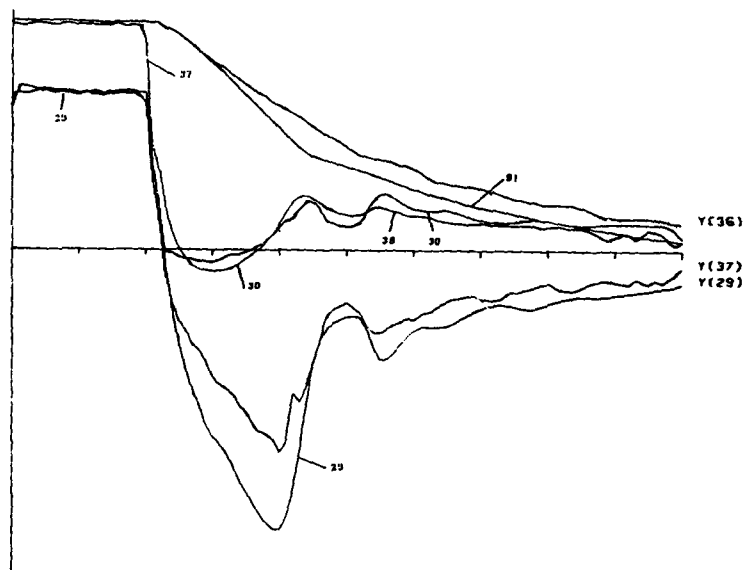
ACKNOWLEDGEMENTS

REFERENCE

(1) A. Duberley, "Considerations Leading to the Development of a Machinery Control Evaluation Centre", 5th Ship Control Systems Symposium, October, 1978.

D1 3-8

Trace	Parameter	Scale Maximum Value
55	TRIALS PITCH RATIO	
35	TRIALS FUEL FLOW	
94	SIMULATION SHAFT SPEED	
33	TRIALS SHAFT SPEED	
X Axis	TIME	

Y(94)
Y(33)
Y(35)

Figure 1 - Simulation Model Validation Study
Shaft Characteristics
Crash Stop Manoeuvre

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Trace	Parameter	Scale Maximum Value
30	SIMULATION TORQUE	
38	TRIALS TORQUE	
29	SIMULATION THRUST	
37	TRIALS THRUST	
91	SIMULATION SHIP SPEED	
36	TRIALS SHIP SPEED	
X Axis	TIME	

Figure 2 - Simulation Model Validation Study

Ship Characteristics

Crash Stop Manoeuvre
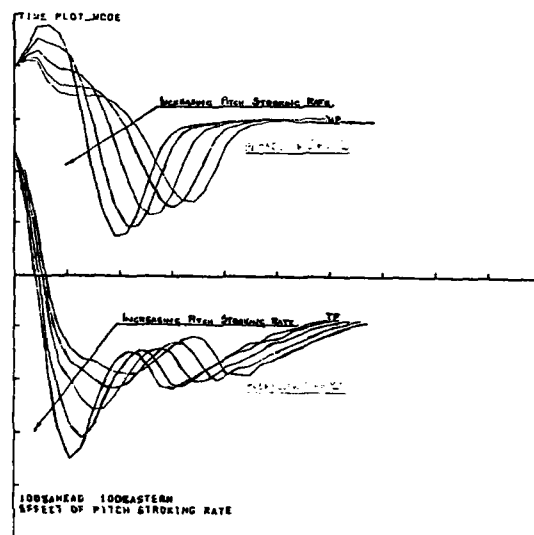
Figure 3 - Propulsion Control System
Parametric Sensitivity Analysis

MMI = Man/Machine Interface
SCC = Ship Control Centre
PCU = Plant Control Unit
SCU = System Control Unit
CPP = Controllable Pitch Propeller
OD = Oil Distribution
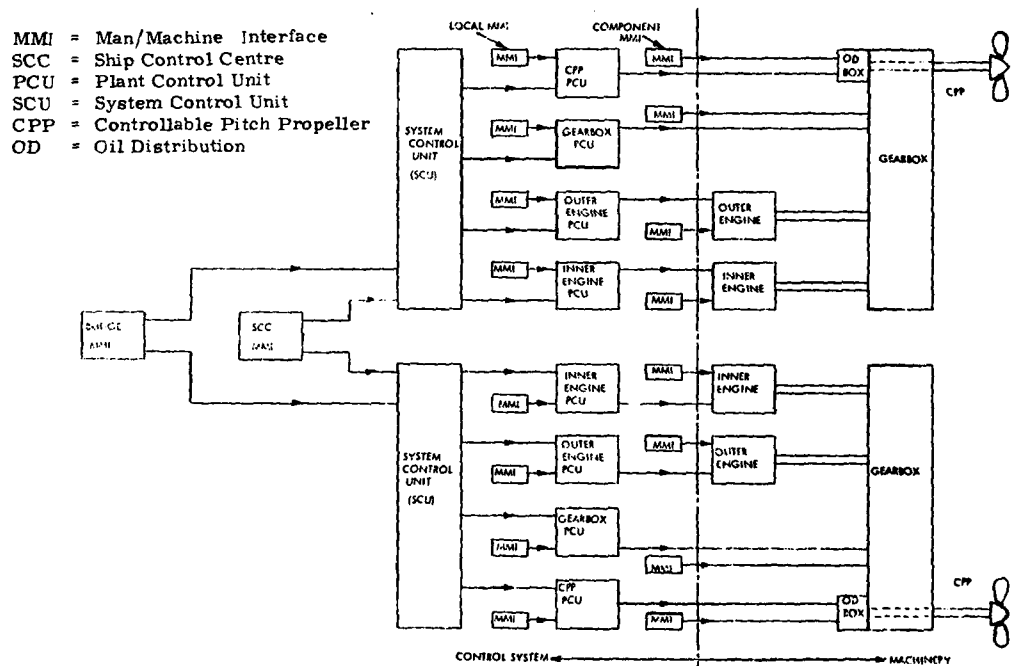
Figure 4 - Distributed Digital Control System.

CRASH STOP MANOEUVRE.

STARBOARD FUEL SYSTEM FAILURE.-

CLOSURE OF HPSOC. AT 5 SECONDS
AFTER START OF MANOEUVRE.

EFFECT ON SHAFT SPEED, FUEL FLOW
AND PITCH ANGLE TRANSIENTS.
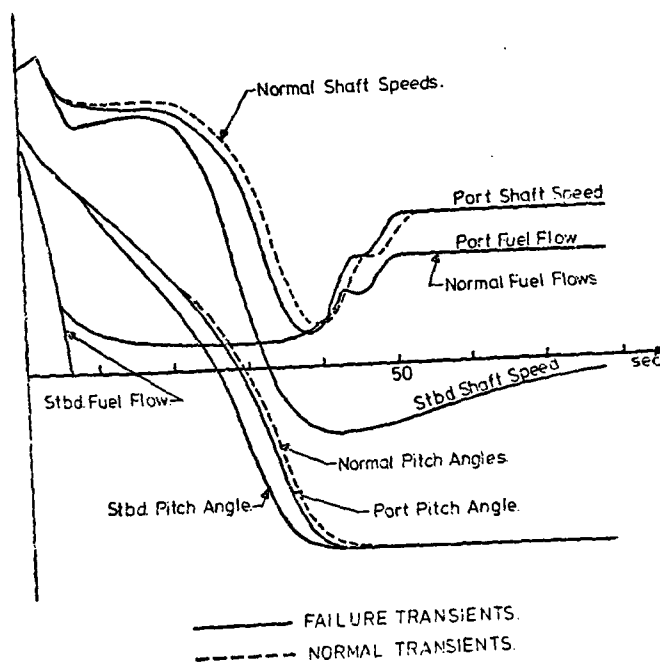
Figure 5 - Gas Turbine Failure Mode Effect

D1 3-12

A NEW INTEGRATED MONITORING SYSTEM

by Lyle W. Ferguson, P.E.
TANO Corporation

ABSTRACT

This paper describes the propulsion control and monitoring system developed by TANO Corporation for the American President Lines, Ltd., containerships currently under construction at Avondale Shipyards, Inc. The system incorporates both conventional alarm and monitoring functions and a Plant Management System (PMS) that uses a distributed processing microcomputer and minicomputer combination to provide monitoring and data/alarm logging. The PMS includes multiple-color cathode-ray tube (CRT) displays and continuous storage of plant performance data on magnetic tape cartridges for off-line trend analysis.

The paper also describes the development of system partitioning into vital (conventional) and non-vital (PMS) subsystems, power distribution design, and the PMS system. Discussion of the PMS will illustrate the use of the distributed processing scheme within the console, the menu format used for operator interface, and the hardware methods which ensure partial system operation if the host or satellite computers (CPUs) fail.

Color graphics on the CRT units provide operators with complete information concerning particular systems (for example, lube oil purification). Implementation and development of PMS graphics is discussed in detail. The PMS discussion includes details of the joint experiment by the shipyard, shipowner, and TANO to provide a remote color CRT in the engineers' quarters.

Maintenance and diagnostic features and system reliability are discussed. Features included in the system to allow the operator or technician to perform system checks are also explained.

The development of computer controls in ship propulsion systems is discussed and compared to the development of computer control pipeline systems. A discussion of the evolution of pipeline systems provides a thesis from which to forecast the future of shipboard systems.

INTRODUCTION

This paper presents the design and system features of the Propulsion Control and Monitoring system supplied by TANO Corporation for the new American President Lines, Ltd., containerships being constructed at Avondale Shipyards, Inc., in New Orleans, Louisiana, U.S.A. The system supplied is in the form

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of four consoles: two in the machinery space control room and two in the pilothouse. This is a relatively extensive system, with over 1200 points monitored and displayed. It is one of the larger systems yet built by our company. This system will monitor one of the first slow-speed diesel installations to be operated by American President Lines, Ltd. Thus, it was decided to provide extensive remote monitoring capability for these ships.

The following sections of the paper will briefly describe the ship, vital and non-vital console systems, and details of the vital and non-vital monitoring systems. We shall describe the computer system and CRT system used and provide some thoughts about the future of marine systems as an extension of contemporary shore-based systems.

The system supplied to American President Lines, Ltd., includes the following major subassemblies.

1) Engine Room Console (ERC)

2) Liquid Transfer Console (LTC)

3) Watch Officer's Console (WOC)

4) Conning Console (CC)

5) Engineers' Accommodation Panels (EAP)

6) Fire Panel (FP)

7) Bow Thruster Panel (BTP)

8) Fuel Fill Station Panels (FFSP)

9) Loose Parts

10) Spares

11) Trend Data Analysis Computer

The ERC and LTC are located in the main engine control room on the port side of the ship at the 32'-7" level and are arranged so that the operator is facing inboard (the machinery space can be seen through glass windows located behind the console). The WOC and CC units are located in the bridge area at the 113 foot level, both facing forward. It is expected that the Trend Data Analysis Computer will be located in the Chief Engineer's office area. The unit is relatively portable and can be moved to the Main Engine Control Room if desired, or used on land.

The ERC and LTC are each contained in modular, 11-gage steel structures which support all components, wiring, and printed circuit modules. No external equipment cabinets are needed. All transducers are located in the machinery space. The Bridge consoles (WOC and CC) are also fabricated of 11-gage steel. All equipment is mounted within the consoles. The various auxiliary

panels are mounted in NEMA 4 and NEMA 12 enclosures depending on location and function. Figure 1 is a photograph of the second shipset ERC and LTC in the final assembly area at our plant.
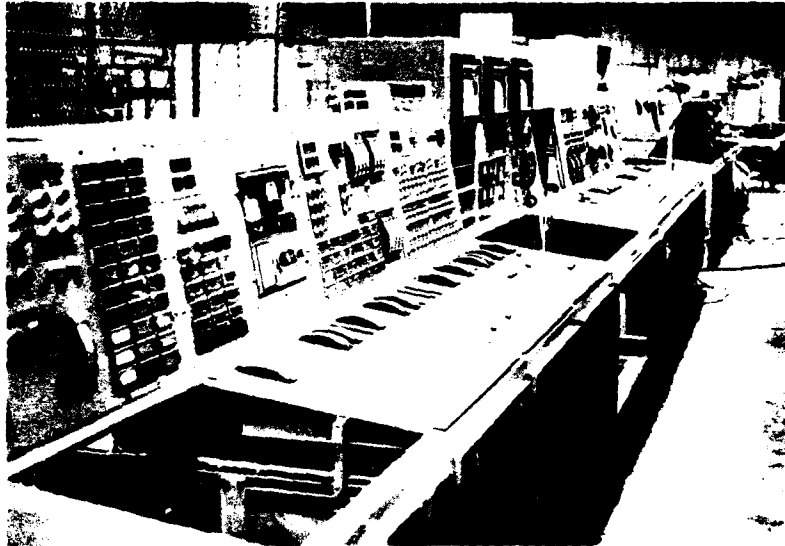
These consoles are currently being checked out on board ship. Sea trials are expected to take place in the spring of 1982.

SHIP DESCRIPTION

The American President Lines, Ltd., containerships are single screw, 860 feet (approximately 265 meters) long overall, and displace 39,900 long tons. The ships carry Avondale Shipyards, Inc., designation C9-215 and are designated MARAD hull numbers 348, 349, and 350.

The 12-cylinder Sulzer 12RND90M engines are rated at 43,200 hp (metric) at 126 rpm. The engines have a 900-mm bore and 1550-mm stroke. Brown-Boveri turboblowers provide a scavenge air pressure of 27.6 psi (1.90 bar) at rated power conditions. Projected fuel consumption on the engine is 0.34 to 0.36 lb/bhp-hr (150-160 gr/bhp-hr). Auxiliary heating is obtained from an engine waste heat boiler and a fully-automatic fired boiler. The generating plant consists of three 2500-kw diesel plants and a 1500-kw steam turbogenerator. A 1500-kw emergency diesel generator plant is also provided. All cooling water pumps, fuel oil pumps, and other vital auxiliaries are fitted in duplicate with auto-start systems. This duplication ensures redundancy and is a USCG requirement for unattended machinery plant operation.

SYSTEM SUBDIVISION

Early in the planning stages of this system, it became apparent that a computer system would be required for the extensive data and alarm logging, trend data collection, and CRT displays desired. The typical design question is whether or not all the alarm systems should be handled by the computer hardware and software. If all alarms and monitoring are operated by the computer (known as a scanning system), the possibility exists that a single CPU (central processing unit) failure can disable all functions. This is obviously not a situation that is desirable, especially with the trend toward reduced manning.

A typical way of overcoming the possibility of disabling the computer systems is to install a backup CPU with automatic changeover capability in event of failure. Since the CPU is not the only "link" in the data acquisition and display chain, the backup system approach can be taken as far as one desires. Systems have been built with backup CPUs, storage discs, etc., all the way to end elements such as transducers. In the planning stage, system cost has to be considered along with probable failure modes and overall reliability; at this point, judgements are made which usually lead to system configurations which meet functional requirements and cost constraints.

The choices made for this system have led to a system design which is divided into vital and non-vital subsystems. In general, the vital system performs the alarm and monitoring functions required by USCG NVIC 1-69, "Guide for the Automation of Main and Auxiliary Ship's Machinery" and the non-vital systems (PMS-Plant Management System) performs all other alarm and monitoring functions.

The vital system is constructed around TANO's Series 79 printed circuit module family, which provides a complete signal conditioning and alarm function on each printed circuit module. This hardware is already in service in several marine applications.

The non-vital system is designed using TANO's high density IRTU/TDAC SCADA hardware, which has been proven in pipeline monitoring and control applications. This hardware line has also been applied successfully on a barge-mounted LNG plant, which has been operating in Indonesia for several years. The non-vital system includes a Digital Equipment Corporation (DEC) LSI-11/23 16-bit minicomputer, two Intelligent Systems Corporation (ISC) color CRT displays, two Xerox printers, and a DEC TU-58 magnetic tape cartridge drive. These units were all selected based on past experience with either these particular items or similar equipment from the same manufacturer. NOTE: DEC and LSI-11 are registered trademarks of Digital Equipment Corporation.
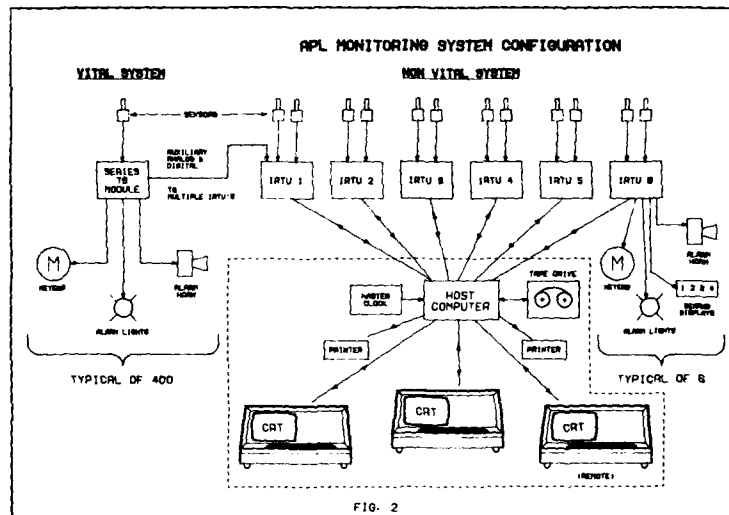
FIG. 2

Figure 2 shows the system configuration and illustrates the interconnects between vital and non-vital systems, the IRTU (intelligent remote terminal unit), and the host computer. The vital system (shown on the left side of Figure 2) is connected directly to all vital sensors. Each Series 79 module incorporates a signal conditioner and alarm logic to drive annunciator lights and horns directly, and includes first out and summary alarm capability. Auxiliary outputs for analog and digital data and alarm logging are connected to the non-vital system IRTUs.

The non-vital system consists of six primary data acquisition and display units (IRTUs), the host computer, and the output and command devices attached to the host computer. The IRTUs accept analog and digital data from sensors and from the non-vital system. Each IRTU includes a microcomputer which allows it to function in a stand-alone mode. The IRTU provides the following functions without aid from the host computer:

1) Alarms for both analog and digital data types.

2) Analog meters for selected points.

3) Demand displays for all points in the IRTU, including changeable setpoints, deadband, and time delay. English/metric unit conversions are included.

4) Self diagnostics of IRTU, CPU, and signal conditioning hardware.

5) Self-monitoring of CPU failure.

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Each IRTU is connected to the host computer using RS232 serial communication lines. These lines are used to transmit to and receive data from the host computer. The host computer "polls" the IRTUs in a "round-robin" fashion to gather all field data for display and logging purposes.

The host computer communicates with the following peripheral devices through the serial communications lines:

1) 6 IRTUs - data gathering

2) 2 CRTs - data display and control

3) 2 Printers - logging

4) 1 Remote CRT - remote data display

5) 1 Master Clock - synchronization

6) 1 Watchdog Timer Module - CPU failure detection

These devices and the associated interconnection scheme are shown in the right-hand side of Figure 2.

The vital and non-vital systems are connected in two ways. First, all alarm states and analog values are passed from the vital system to the non-vital system for logging purposes. Second, each IRTU includes a "watchdog timer" in software to create a contact closure every 15 seconds. This contact closure is used as a vital alarm system input. The alarm channel connected to this input is adjusted so that the time delay is greater than 15 seconds and thus only enters the alarm state if the contact fails to close once during the 15-second period. The host CPU has a similar monitor through the vital system. It is connected to a hardware "watchdog timer" module via a serial communication line. If the host CPU fails to send a message to the watchdog timer module every 15 seconds, a vital alarm contact is opened, and the host CPU is declared "failed."

The system subdivision used is designed to allow orderly system degradation without the failure of any one subsystem affecting the operation of the other. By operating the non-vital system in a distributed processing manner, an IRTU can fail without affecting the alarm or display capabilities of the other IRTUs, or the display and alarm capabilities of the host computer. If an IRTU is "off-line" this is detected at the host computer and the message "COMMUNICATIONS FAILED RTU #N" appears on the CRT. If the host CPU fails, each IRTU will continue to operate and all alarm and local display capability will remain; only logging, trend data collection and summary display capability will be lost.

The system subdivision chosen provides the added capability of the computer-driven system and retains the simplicity and reliability needed for the vital alarm and monitoring points. The further subdivision of the non-vital system into intelligent data-gathering subsystems connected to a host CPU provides further protection against a single failure causing the loss of the non-vital alarm and monitoring system.

Vital System

The Concept. The Series 79 Marine Monitoring System was specifically designed to provide reliable monitoring and annunciator operation in a shipboard environment. Simplicity is the primary basis of the Series 79 concept.
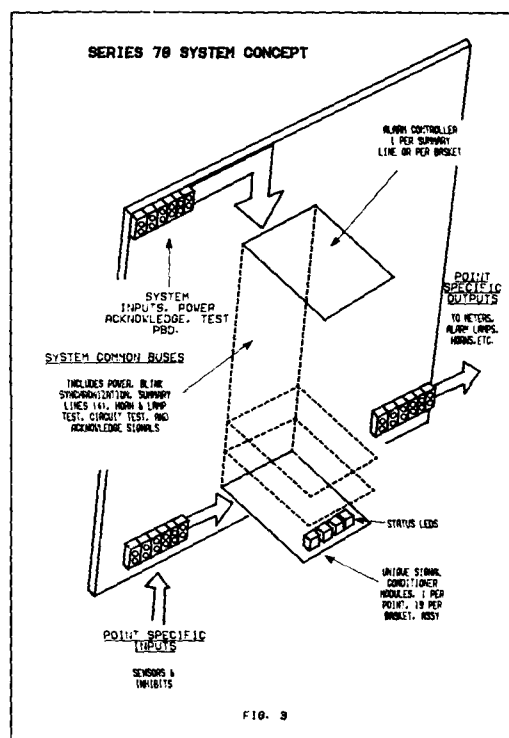
Overall system design, including component selection, is directed toward extended operation in the marine environment. Temperature extremes, vibration, position, oily vapors, high humidity and fluctuating power systems have virtually no effect on system operation. Series 79 meets all regulatory body operational and environmental requirements and is suitable for use in unattended machinery space systems. Long system service life is assured by conservative rating of system components for the harsh marine environment. Liberal use of military grade components and conformal coating of electronic circuits assures high reliability.

Except for common-function buses such as lamp test, alarm acknowledge, main power, etc., each module is totally independent of all other modules in the system. Each module is essentially self-contained. A monitoring module failure can only affect one parameter, thus simplifying the location and repair of the offending circuit.

The Series 79 system consists of a monitoring interface basket, ten individual monitoring modules, and the system descriptive, application, and maintenance documentation. Support items such as power supplies, meters, indicators, etc., are selected from numerous readily available standard sources by the system designer to satisfy individual system specifications. System sensors are also selected by the system designer to fit particular applications.

The monitoring interface basket contains the Series 79 modules and provides both interface terminals for ship's wiring from sensors and terminals for connection to the console display devices. This unitized construction minimizes console and panel wiring. The monitoring interface basket easily mounts on bulkheads within consoles and panels, and provides ready access to the modules for servicing. All modules plug into the backplane and can be quickly removed and replaced. Digital programming switches located at each module position on the monitoring interface basket allow the module functional features to be tailored individually. Since these switches are on the basket, programming is assigned to the position and not the module. Should it be necessary to replace a module, no changes in programming are required to make the replacement module perform like the original module.

Test points and adjustments on Series 79 modules simplify calibration requirements. Light emitting diodes (LEDs) are incorporated on the front of the modules to provide instant operating data without having to remove the module. Ease of calibration and servicing are key aspects of all system module designs. The system arrangement is shown in Figure 3.

SERIES 79 SYSTEM CONCEPT

ALARM CONTROLLER
1 PER SUMMARY
LINE OR PER BASKET

POINT
SPECIFIC
OUTPUTS

TO METERS,
ALARM LAMPS,
HORNS, ETC.

SYSTEM
INPUTS, POWER
ACKNOWLEDGE, TEST
PBO.

SYSTEM COMMON BUSES

INCLUDES POWER, BLINK
SYNCHRONIZATION, SUMMARY
LINES (4), HORN & LAMP
TEST, CIRCUIT TEST, AND
ACKNOWLEDGE SIGNALS

STATUS LEDS

UNIQUE SIGNAL
CONDITIONER
MODULES, 1 PER
POINT, 19 PER
BASKET ASSY

POINT SPECIFIC
INPUTS

SENSORS &
INHIBITS

FIG. 3

Series 79 modules are divided into three functional categories: analog monitoring and alarm; contact alarm, alarm control, and summary alarm; and setpoint-status/alarm. Each of these module groups is designed to satisfy specific marine monitoring and alarm applications requirements. Typical module block diagrams are shown in Figure 4.

TYPICAL SERIES 79 MODULE BLOCK DIAGRAMS

FIG. 4
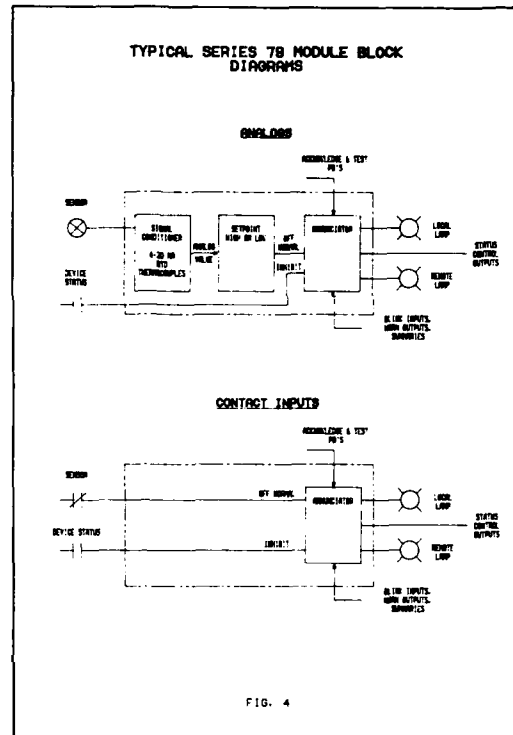
Analog Modules. Analog monitoring and alarm modules provide for continuous or demand display of a process parameter and a high or low alarm function. Series 79 modules are available for 4-20 mA, type-J thermocouple, 100 Ohm Nickel or Platinum resistance temperature detector (3-wire), and 10 Ohm Copper resistance temperature detector (4-wire) process sensors. This allows for the monitoring of pressures, temperatures, levels, flows, and other process parameters. Each of these modules contain a signal conditioner/linearizer circuit, a setpoint (alarm trip) circuit and a complete annunciator circuit. Thus, all required electronic circuitry for a single monitored point is contained on one plug-in unit.

Analog monitoring and alarm modules have separate outputs for analog displays and alarm indication. All analog modules have a master zero and span adjustment to provide for overall calibration and a separate meter span adjustment to compensate for the relatively poor tolerance of analog meters. In addition, setpoint and deadband adjustments are provided to set the alarm trip point

and reset point. A test point on the module allows the setpoint value to be read on any common test multimeter. This allows the setpoint to be readily set without the need to exercise the process or connect simulation equipment to the input terminals. Each analog monitoring and alarm module contains an alarm circuit which is essentially identical to the contact alarm module circuit described below.

Contact Alarm Modules. Contact alarm, alarm control, and summary alarm functions are provided by three separate modules. The contact alarm, whose circuits are also included in the analog monitoring and alarm modules, is used to provide an alarm function from a switch type input. Each alarm circuit is also fitted with an inhibit input which is used to prevent the alarm from sounding under specific conditions, such as when equipment is deliberately secured. Alarm circuits contain numerous installed options such as "first out/non-first out", "sealed/un-sealed", and common/independent horn and lamp acknowledge. These programmable options allow the system to be tailored to specific operating requirements.

The alarm controller is utilized to provide alarm support functions common to all system annunciators. These functions include a synchronized blink rate, vital and non-vital audible annunciator drive, and buffering of the system test and acknowledge buses. A typical system requires just one alarm controller.

Where remote indication of the activation of local alarms is required, the Series 79 summary alarm module is utilized. This module is ideal for summary alarm monitoring of the ship's propulsion plant on the bridge.

Setpoint/Status Modules. The setpoint-status/alarm group contains three highly specialized modules which are used in less common functional applications. These functions include multiple setpoints and alarms for a single parameter, digital control based on a process setpoint, and operator variable setpoints.

Power Requirements. Series 79 systems utilize a source of nominal 24 VDC to satisfy all operating power needs. Each module contains its own power regulator, thus permitting wide swings in the 24 VDC service voltage. Each monitoring interface basket contains a main fuse and power failure indicator. Module ship interface lines are fuse-protected from short circuits and overloads.

Module Removed Alarm. It is possible to configure a system to declare an alarm when a module is removed from a basket. The Module Removed Alarm module provides a feedthru-function for unused slots, if this function is required. All other modules have feed-thru jumpers in one pair of backplane connections. This type of module may be connected to a contact input to cause an alarm if a module is removed from any basket in a system.

Status Indicators. Light emitting diodes (LEDs) are placed on each module to provide the operator with an easy method of

checking field and console component status in the event of a malfunction within the system. These LEDs function as follows:

1) Status (Yellow) - indicates the state of the field sensor. If the system is configured for normally closed contacts, this LED is illuminated when the contact is open. For analog inputs, the LED indicates that the annunciator circuitry on the module is receiving an off-normal signal.

2) Horn (Red) - indicates an unacknowledged alarm horn.

3) First Out (Red) - indicates that a module is holding the first-out bus signal.

4) P Summary (Red) - flashes momentarily when alarm occurs to indicate assertion of the summary bus.

5) S Summary (Yellow) - indicates the state of the output driving the summary bus.

Non-Vital System

Capabilities. The non-vital (PMS) system provides the following functions:

1) Signal conditioning and alarm indication as indicated by machinery space sensors. This includes sequential horn and lamp acknowledge summary alarms and first out notification.

2) Demand digital display for all points within the non-vital system, including variable alarm setpoints, time delays, deadbands, and English/metric conversions.

3) CRT displays including point pages, graphics pages showing real-time system data superimposed on system piping diagrams, trend data displays, system configuration pages, engine performance displays and "help" pages.

4) Printed logs including data and alarm logs, alarm summary logs, pump run time records, and backup bell logging.

5) Trend data collection and storage of data on magnetic tape cartridges.

Each capability will be explained in detail in the following paragraphs. All of the functions described are actually performed by software operating either in the IRTUs or the host computer.

Signal Conditioning/Alarms. Software in the IRTU implements the same functions previously described for the Series 79 hardware. All machinery space points are scanned at three-second intervals. Analog values are scaled and compared to setpoint values; if values exceed setpoints, the point is declared as an alarm. Contacts are checked for status and compared against a table of acceptable states adjusted for the effect of any inhibit

information. After all points have been checked, time delays are
considered. If points have been in the alarm state long enough,
alarm indicators are illuminated and the alarm horn is turned on.
Acknowledge, first-out and summary sequences are also included to
duplicate the vital system features. Data is sent to the host
computer indicating which points are in alarm and which are in
alarm unacknowledged. A message will appear on the CRT indicating
"ALARM ON PAGE SW." The operator can type the characters SW on
the keyboard and a text display of the point in alarm will appear
on the CRT. The host computer will print an alarm log in red on
the printer. Other logs in progress will be interrupted
momentarily while the alarm log is printed. After the alarm has
been acknowledged, the special CRT message will disappear although
a "point log" on the CRT will continue to show the point in the
alarm state until the alarm has been cleared.

     Demand Displays. The demand display unit includes a 6 1/2
digit digital display, a three digit address thumbwheel, a four
digit setpoint thumbwheel, three LED unit indicators, and six
momentary switches to allow the operator to examine and modify
non-vital system setpoints, deadbands and time delays. The
address of a point may be dialed into the address thumbwheel and
the current value will be displayed on the digital display.
Analog values are automatically scaled for maximum resolution;
digital values (contact inputs) are displayed as "0" or "1."
Setpoints, deadband and time delays may be examined using the
"Display" switches. Values may be changed by entering the new
value into the value thumbwheel and depressing the "Load" switch
momentarily.

     Diagnostic functions include a quick check on overall IRTU
status by dialing address "000" into the demand display
thumbwheels. A repetitive pattern of hexadecimal digits will
indicate that the IRTU CPU is operating. If a "calibration in
progress" switch is actuated, other special addresses can be used
to drive either individual meters or all meters to values selected
by the value thumbwheels.

     CRT Displays. CRT displays are generated by the host
computer using data transmitted to the host computer from each
IRTU. The operator may select "pages" from a "menu" which
displays the choices available. There are three basic types of
data available to the operator via the CRT. One type displayed is
the host computer configuration pages. This display allows the
operator to set the time and date, recall a "data base" generated
for special operation conditions, or copy tapes.

     A second type of data available is in the form of tabular
pages, as shown in Figure 5. Data logs, point displays, trend
data displays, alarm summary logs and pump run time logs are
available in this format. Data logs and point displays are
"snapshots" of the data - the displays are not updated in
real-time. Trend data displays are generated from data being
collected to calculate four-hour and 24-hour averages. They may
be recalled from tape either by day or by full tape.

Figure 5

The third display available is the system graphic display which is a real-time display. Figure 6 shows one of the real-time displays. These displays show pump, valve, and process status on graphic displays developed from actual piping diagrams. Tank levels are shown as bars whose height is proportional to tank level. The symbols on the diagrams change color to indicate status; open valves or running pumps are shown in green, closed valves or off-line pumps are shown in red. Analog values, such as pump discharge pressures, are shown in red if values exceed alarm setpoints. Each display is updated every 10 seconds. All displays may be seen on either CRT as the operator desires.
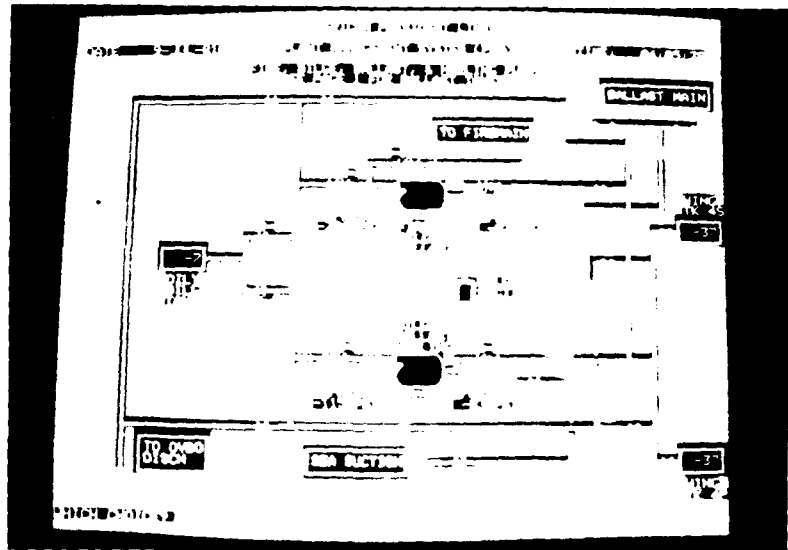
Figure 6

An additional real-time display is the engine performance
display. This display plots instantaneous specific fuel flow vs
brake mean effective pressure and allows the operator to compare
performance against trials data. The calculations include actual
fuel flow, shaft RPM, and horsepower with corrections for ambient
temperature and pressure, fuel heating value, cooling water
temperature, and charge air temperature.

Printed Logs. Automatic logs are available at preset
intervals of from 1 to 24 hours and include alarm summary (first
40 alarms in the interval), pump run times and averaged data
(4-hour and 24-hour).

Trend Data Collection. Trend data is collected on
approximately 390 points selected by the owner. Average values
are calculated on these data. Every four hours the average values
are stored on magnectic tape cartridges. Twenty-four hour
averages are also developed and stored. No calculations are
performed on the data. The raw data is stored and will be
interpreted by ship's personnel or by on-shore personnel. The
data may be examined by "dumping" it to the CRT or printer.
Either a particular day or a whole tape may be selected. A later
addition to the system is a "trend computer" which will allow an
operator to select a particular point in the data and display all
days of that data for comparison purposes.

IRTU Hardware. The signal conditioning and data acquisition
(SCADA) functions of the non-vital system are accomplished using
six IRTUs (Intelligent Remote Terminal Units) located in the rear
of the ERC and LTC. Each IRTU performs the signal conditioning,
alarm, and data display functions previously described. The IRTUs
were developed using a combination of two TANO product lines: the
Outpost microcomputer products CPU and the TDAC data acquisition
system hardware.

The Outpost microcomputer product line is centered around the
Motorola 6800 (and its derivatives) 8-bit microprocessor and
includes the following modules.

1) Central Processor - microprocessor

2) Power Regulator

3) Maintenance Controller - interfaces with address and data
    register panel

4) Bus Controller - memory refresh, bootstrap loader,
    real-time clock

5) Memory - random access memory (RAM), 64K bytes maximum

6) Memory - read-only memory (ROM), 64K bytes maximum

7) Serial Line Interface - communications

8) TDAC Interface - data acquisition

In this application, the processor is operated at a 1 Mhz
clock rate. Memory available includes 32K bytes of RAM and as
much as 32K bytes of ROM. Communication within the console is
configured for a rate of 2400 baud. The TDAC hardware system
consists of a group of data acquisition and interface modules
which allows the CPU to acquire both analog and digital data. The
modules utilized in the system include the following:

1) Group Selector - module row selector

2) Analog-to-Digital (A/D) Converter

3) Digital-to-Analog (D/A) Converter

4) Isolated Analog Multiplexer - 8 channel

5) Isolated Status Input - 32 channel

6) Thermocouple Signal Conditioner - 8 channel

7) Latching Command Output - 16 channel

8) Lamp Driver - 32 channel

9) RTD Signal Conditioner

10) Momentary Command Output

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The system is designed to appear to the CPU as an ordinary block of memory. The CPU can write commands to and receive information from each location using standard CPU operations. As used in the IRTU, the data acquisition system appears as a 512 byte memory port and allows access to up to 256 analog points and 2048 digital points in a typical IRTU. Digital points can be scanned at a rate greater than 500 points per second; analog points can be scanned at up to 75 points per second. All scanning rates depend on software but tend to be limited by the A/D conversion and multiplexing delays.

IRTU SYSTEM PACKAGING
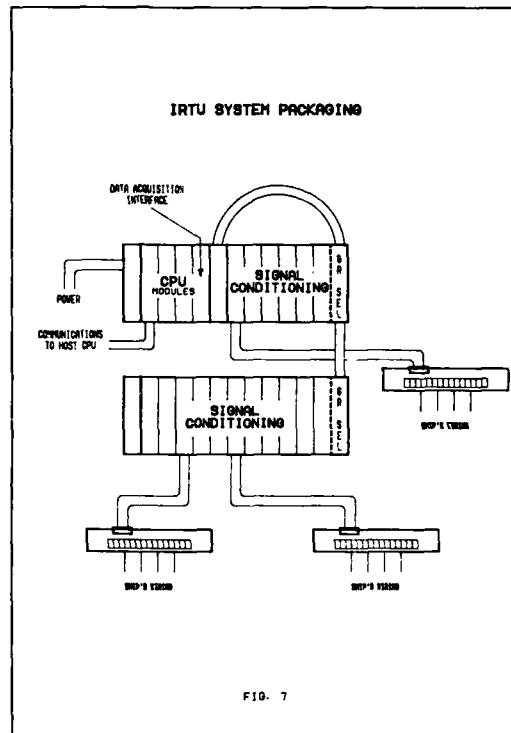
FIG. 7

The packaging scheme used for the IRTUs consists of a combined CPU/TDAC module basket associated with "expansion" TDAC baskets. Additional rack-mounted auxiliary components include a maintenance panel and power distribution assembly. Interface with ship's wiring is accomplished via I/O "frames" which connect to ship's wiring on one side and to multi-conductor flat cables (from signal conditioning modules) on the opposite side. This is illustrated in Figure 7.

This system has proven to be very versatile. The rack mounting provisions of all components including I/O frames, allows field wiring access to terminal strips while providing a high density flat cable connection to the appropriate signal conditioning module.

Hardware troubleshooting is accomplished using the maintenance panel provided as part of each IRTU. This panel may be used to examine data at operator-selected locations in the IRTU and may deposit data at operator selected locations. This feature may be used with the processor running or halted. For example, if the state of a contact input is questionable, the switch panel may be used to look at a bit in memory which represents the state of the contact. A light on the maintenance panel will be on or off depending on contact state.

IRTU Software. Software for the IRTUs is written in Motorola 6800 assembly language and consists of tasks which operate under priorities and schedules set by TANO's MIDGET real-time executive. The tasks are as follows.

1) Initialization

2) System clock, 1/60th of a second and seconds

3) System clock seconds

4) Poll digitals, accumulators and analogs

5) Poll analogs

6) D/A driver

7) Into alarm and out of alarm

8) Local display

9) Poll ship speed

10) Local command (maintenance panel)

11) Receive communications

12) Communications

13) Ballast heeling system

This software operates with a default data base which is stored in ROM. The default data base contains all preset alarm setpoints, time delays and deadbands. The system will restart automatically, using these values after a power failure or after a manual reset. Operator-modified setpoints, etc., can be saved on tape by the host computer and recalled to "downline load" each IRTU, if desired. All operating programs are stored in ROM; no program "downline loads" are necessary.

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The communications protocol includes many message types but only a few will be discussed here. (It should be noted that all communications are initiated by the host computer.)

1) Exception Report - The IRTU sends the host computer data concerning only those points which have changed since the last "poll" of the remote.

2) All Data Report - The IRTU sends the host computer all data concerning all points in the IRTU.

3) Downline Load - The IRTU accepts a message from the host computer containing setpoints, time delays, and deadband to substitute for default values.

4) Special Status - The IRTU sends the host computer a message stating whether it needs to send an Exception Report or an All Data Report.

The communication scheme employed is designed to minimize the time which elapses between host CPU updates by reducing message lengths. The typical message length will be only 25 - 50 characters long and will report only those items which have changed since the last message. At five minute intervals, the host requests All Data Reports from each IRTU to be sure that all host CPU points have been updated. With this scheme and a 2400 baud communications rate, all IRTUs are polled within a 10-second interval. An alarm occurring in an IRTU will usually require no more than one to two seconds to be printed on the alarm log and to appear on the CRT.

The alarm logging feature provides a first-out feature which "tags" the first of a group of alarms which appear virtually simutaneously. The first alarm of a group will be noted in three ways.

1) The indicator associated with the first alarm will flash at twice the rate of the indicators for later alarms.

2) Point logs on the CRT will denote the first alarm with an asterisk on the left side of the data entry for that point.

3) Printed logs will include a red asterisk in the same manner as CRT-presented data.

The first-out features implemented will help an operator to determine the event which initiated a sequence of alarms.

Host Computer Hardware. The host computer consists of the following major components as shown within the dashed lines in Figure 2.

1) Host Computer - Digital Equipment Corporation LSI-11/23 with 128K words of 16 bit memory - located in the ERC.

2) CRT Terminals (2) - Intelligent System Corporation 8100G Color Graphic CRTs with keyboards - one each located in the ERC and LTC.

3) Printers (2) - Diablo 60cps "daisywheel" printers - one each located in the ERC and LTC.

4) Tape Drives (2) - Digital Equipment Corporation TU-58 Tape Cartridge Drives - located in the ERC.

The host computer includes the CPU and memory modules, a bootstrap ROM module with two communication ports, and additional four-channel serial communications modules for a total of 14 serial communication ports. No non-DEC modules are needed in the host computer.

Host Computer Software. The host computer software is written in MACRO-11 assembly language and operates with the Digital Equipment Corporation real-time executive, RSX11S. All software assembly was performed on a Digital Equipment Corporation PDP11-34 system. The software is subdivided into various tasks as listed below.

1) CRT/Keyboard Tasks

    a) Command Processor - processes operator input from the keyboard.

    b) Real-Time Page Generator - displays system diagrams and updates values.

    c) Static Page Generator - displays tutorial pages.

    d) Efficiency Page Generator - displays engine performance data.

2) Clock Based Tasks

    a) GM Time - reads the bridge located master clock.

    b) GM Time 1 - compares the bridge located master clock to internal computer clock and automatically corrects the internal clock.

    c) Watch - schedules other tasks.

    d) Control - starts-up, causes display refresh and automatic logs.

3) Tape Operations Tasks

    a) Save - saves average data.

    b) Dump - recovers average data.

    c) Data-Base Save - saves system data-base for recall.

4) Data Gathering Tasks

    a) Pump - acquires pump run time.

b) Scan - communicates with IRTUs and processes alarms.

c) Krunch - updates averaged data.

d) Load - downline loads IRTU data-base.

5) Logging Tasks

a) CRT Log - provides text logs to the CRT.

b) Print Log - provides text logs to the printer.

c) Bell Log - provides bell logging to the printer when initiated by operator.

The software includes a "Help" page to provide new operators with operating instructions and allows the more experienced operator access to the RSX11S operating system. The host system is designed to support a third CRT located in the engineers' quarters. During periods of unattended machinery space operations, the system can be configured to "redirect" one of the CRT tasks to operate using a remote terminal located in the engineers' quarters. It will thus be possible to monitor machinery plant conditions without leaving the quarters.

POWER DISTRIBUTION SYSTEM

FIG. 8
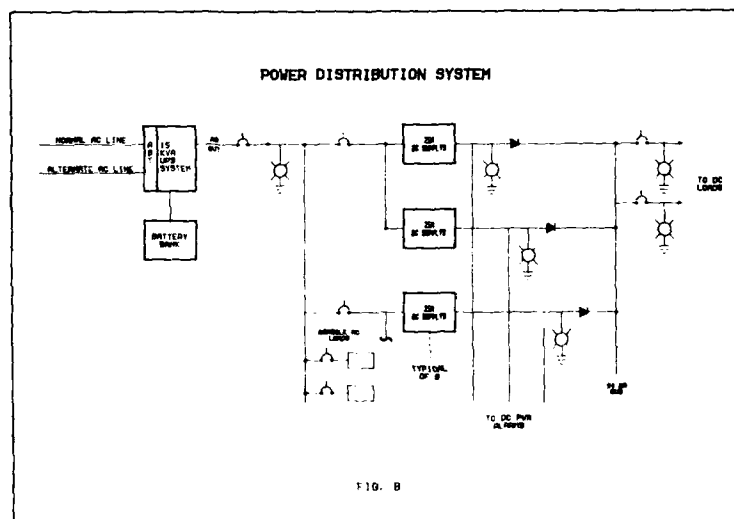
Power Distribution

    The power distribution system for the system has been
designed to provide the following features to ensure a reliable
power system.

    1) Automatic bus transfer upon failure of the primary AC
        source.

    2) No-break power for 30-minute operation if all AC sources
        fail using static UPS (uninterruptible power source) with
        batteries.

    3) Automatic switching to bypass the UPS in case of UPS
        failure.

    4) Multiple DC supplies, sized so that failure of any two
        will not disable the system.

    5) Alarms to notify the operator of failure of any single DC
        supply.

    6) DC circuit breakers on all console subsystems.

    Figure 8 illustrates the system as designed. The DC supplies
selected are the ferro-resonant type which we believe to be the
most reliable type of regulating supplies available. These
supplies provide adequate regulation and can be short-circuited
indefinitely without damage.

Ballast Heeling System Controls

    IRTU 6 (in the LTC) includes a control system designed to
provide automatic ballasting during in-port cargo handling
operations. Dual list sensors are mounted within the console and
are used to sense list angle. The software within the system
checks ballast (wing) tank levels and will automatically align
valves before starting the 6000 GPM Ballast/Heeling pump. The
system is capable of aligning valves for tank-to-tank,
tank-to-sea, and sea-to-tank pumping conditions.

    The system includes numerous event completion checks to
verify that valves have reached specified states within allowable
times, that pump discharge pressure is present, and that list
correction is actually occurring. Failure to meet any of these
conditions will result in pump shutdown: valves will be commanded
to close, and the system will return to manual control. An alarm
signals the operator that a system failure has occurred. In
addition, the operator may take manual control at any time.

    The software for this system includes a feature to allow easy
modification of timeout intervals and pressure limits during
trials. Although default values are stored in ROM, these values
are transferred to RAM during system operation and, consequently,
can be modified using the IRTU maintenance panel.

Pump Controls

Dual pump systems are provided with standby controls which will automatically start the off-line pump if discharge pressure falls below preset minimums. "RUN", "STBY", and "STOP" controls are provided for each pump of a pair. The "RUN" pushbutton will provide a momentary contact closure to the motor controller and will enable the "STBY" relay of the other pump. The "STBY" pushbutton will stop the pump if it is already running, energize the "STBY" relay, and disable the "STBY" circuit of the other pump. Only one pump can be in the standby condition. The "STOP" pushbutton breaks the holding circuit in the motor controller and removes both pumps from the standby mode.

If both pumps are stopped, depressing the "STBY" pushbutton of one of the pumps will generate a run contact to that pump after a 30-second delay.

If a pump is running and the other pump is in standby, stopping the running pump (using "STOP" pushbutton) will also remove the standby pump from "STBY", thereby preventing it from starting when the stopped pump loses discharge pressure. However, stopping a running pump locally at the motor controller will not prevent the "STBY" pump from starting. This feature is only functional from the console.

The "FAIL" contact from the motor controller causes an audible alarm. The "STOP" indicating pushbutton will flash until the alarm is acknowledged.

APL MACHINERY SPACE CONSOLES

FIG. 9
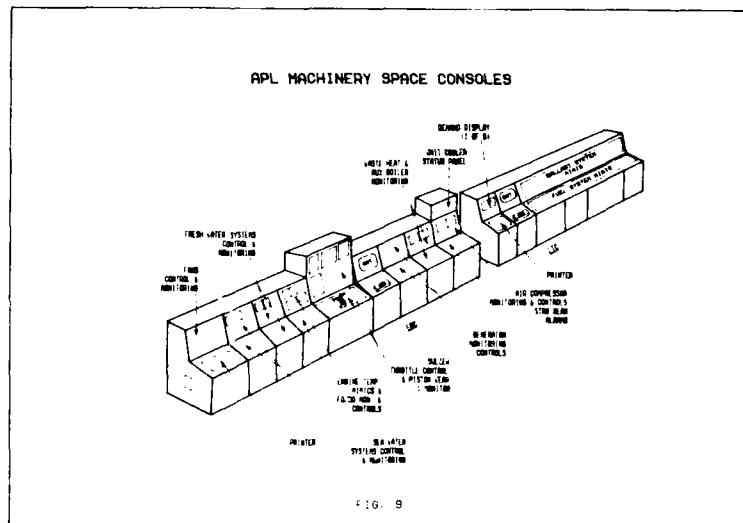
PANEL ARRANGEMENTS

The panel arrangement generally follows the pattern of having operating controls placed on the lower (near horizontal) surface with alarms, meters, and demand displays placed on the upper (near vertical) surface.

Engine Room Console

Engine controls and monitoring, generator monitoring, and other propulsion auxiliaries are located in the ERC. The Sulzer throttle control is placed in the center of the console as shown in Figure 9. All engine temperatures are monitored via the engine mimic to the immediate left of the throttle control section. The CRT is placed to the immediate right of the throttle control to allow the operator quick access to system displays and data without having to walk to the end of the console. The operator may also request system displays concerning ballast tank/fuel oil tank levels without needing to go to the LTC.

Liquid Transfer Console

Fuel oil, diesel oil, and ballast tank levels, and associated pumps and valves are monitored in the LTC. This console includes a mimic arrangement with the ballast tank system located on the upper surfaces and the fuel systems located on the lower surfaces. Fuel oil and diesel oil tank level monitoring include operator corrections for fuel specific gravity and operator variable level setpoints for ease of operation during pumping.

Alarm indicators are placed in several locations, depending on the type of input device. Alarms associated with devices with continuous analog displays (meters) have alarm indicators placed above and below the meters. Alarms associated with contact inputs are generally placed in rectangular arrays with grouping by function. Alarms associated with demand displays are indicated within the pushbutton used to initiate the display.

PACKAGING

The consoles are constructed of 11-gage mild steel without internal framing. They are in modular sections, with each section 37.25 inches (95 cm) long, mounted on a structural channel base, to provide toe space. The assembled consoles may be either bolted or welded in place.

Cooling is provided by fans mounted in the ends of the console arranged to intake through filters at the fans and exhaust through rear door louvers. Fans are used on non-vital system module racks to avoid local hotspots; vital system racks require no fans.

Lockout arms are provided for front and rear doors and console front panels; panels are hinged for access.

SYSTEM EVOLUTION

The system supplied for the containerships is interesting in an historical sense because of the somewhat parallel development of oil and gas pipeline supervisory systems. Pipeline supervisory systems have evolved in four stages as described below:

1) Local remote controls at pumping stations - coordination by telephone; manual backup.

2) Central controls center - console mounted pushbuttons, indicators and meters; automated logging. Local remote backup/manual backup.

3) Central controls center - console plus CRT controls. Computer does logging, batch tracking, leak detection. Local remote backup/manual backup.

4) Central controls center - multiple CRT only; all functions through computer. Backup computer automatically takes over, if necessary. Local remote backup/manual backup.

It appears that current marine systems have evolved to a state between the second and third stages described above. The obvious question is: should shipboard systems procced to the multiple-redundant computer systems already in use in critical land-based applications? I would assume that reduced manning, plus the need to closely monitor fuel consumption, will lead to the use of such systems, possibly in combination with direct gaging for back-up.

ACKNOWLEDGEMENTS

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SHINPADS
AN INTEGRATION PHILOSOPHY FOR THE 21ST CENTURY

Cdr James E Ironside
Canadian Navy

ABSTRACT

SHINPADS, the SHips INtegrated Processing And Display System, is an integration approach to the total ship system which makes use of current trends in embedding intelligence (computers) in almost all elements of a ship to achieve an integration of these elements which is simple, fault tolerant, capable, flexible and supportable. A distributed architecture using redundant data buses as the inter-element communications medium between intelligent devices provides capabilities not previously possible. Although the bus can connect any intelligent devices, both supportability and the ability to reconfigure around damage are enhanced by a comprehensive set of standardized digital processing elements and displays. All elements necessary to construct a SHINPADS system are either in production or in late stages of development.

THE PROBLEM OF SHIP INTEGRATION

Of all the problems facing the designers of naval ships, none strikes more fear, none has more risk, none takes longer, and none has more problems, than ship system integration. There is complexity beyond comprehension in the thousands of wires and interconnections between various systems. Costs are measured in dollars per metre of wire, and more metres mean more dollars. Design changes because of faults mean yet more installation work and more dollars. Even when it has been put together and set to work, it is still not satisfactory. It is vulnerable because it is impossible to replicate this mass of cabling. There are many points of failure where large portions of the ship system can be disabled. It is not particularly capable, as subsystems are unable to use information which would be valuable to them because they are not connected. They are unable to overcome faults by bypassing breakdowns. They are unable to use all of the ship's resources in their task. The systems are inflexible. Most so-called integration is not integration at all, but merely a collection of minor empires. Components are pathologically bound to each other in the system without standard interfaces and thus changes must be massive and expensive, and thus changes are not done. Furthermore the equipments are close to unsupportable. Each peculiar equipment demands its own special technicians, unique training, unique spares, and peculiar shore support.

If we could start from scratch, what would we ask for for ship integration?

a. Simplicity. The system should use standard components and interfaces wherever possible to minimize unique types of equipment. It should use the minimum number of components and wires. The user should have little concern with the mechanisms of integration.

b. Low Cost. It would be nice for the system to be cheapest on a first cost basis. It is essential that it be cheaper on a life cycle basis. This implies reduction of cabling for first cost and the ability to allow equipment change without massive internal wiring change.

c. Redundancy. The integration system should be designed such that no

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single point of failure exists in the system, and, if pos.ible, such that multiple failures will not cause it to cease operation.

d. Capacity. The system should be able to handle not only the initial requirements of the ship system, but should have sufficient reserve capacity to allow upgrading of the equipments and systems over the life time of the ship without requiring a new integration method.

e. Flexibility. The system should impose no restrictions upon the Command's use of the operational equipments.

f. Supportability. The system should minimize requirements for training, for technical support, and for shore infrastructure.

SHINPADS

SHINPADS is an architectural concept that satisfies these requirements. The ship is one system, from engines to guns not just a collection of independent subsystems. Subsystem elements are functions to be done, not tightly bound collections of single purpose parts. Systems are composed of intelligent processes communicating with each other, not a central intelligence giving orders to dumb peripherals. The ship is optimized as a total combat unit. Given this philosophical viewpoint, it is possible to structure a system to achieve simplicity, redundancy, capacity, flexibility, and supportability, in an economic fashion.

PRINCIPLES OF SHINPADS

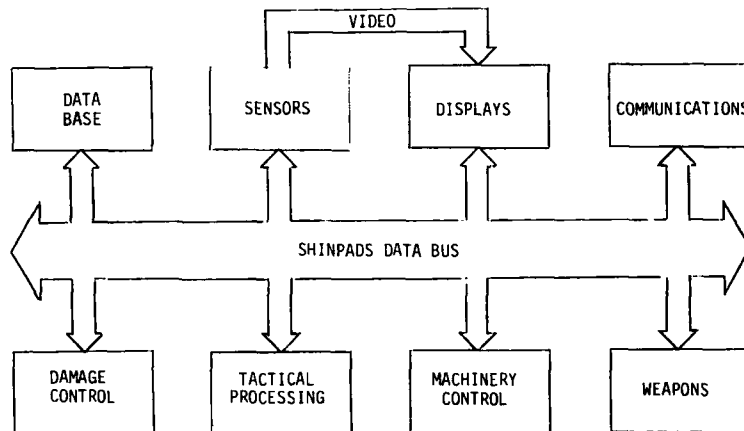SHINPADS can be described in terms of three fundamental concepts.

Figure 1   SHINPADS Architecture

a. A Distributed System. A SHINPADS system is distributed in
    geography, in function, and in control. Only in this way is
    it practical to achieve relative invulnerability to single
    point failures, whether these failures are "normal" or combat
    caused damage.

b. A Data Bus Structure Interconnecting Intelligent Devices. By
    giving all devices access to all of the ship's information, it
    is possible to achieve redundancy of function and sharing of
    work in the face of changing battle needs. It is possible to
    upgrade systems, either by improvement of individual components
    or by replacement and addition of new components, without massive
    wire changes.

c. Standardization in Hardware and Software. Only through standards
    can we manage the escalating problems of designing, building,
    inte grating, and maintaining combat systems. Only through
    standardization can we support the systems through their lives,
    by avoiding needless multiplication of technicans, training,
    spares, and support facilities.

SHINPADS is a ship level optimization. For new equipment, the SHINPADS
concept can be incorporated from the outset and in fact can result in
simplification of development by reducing the scope of equipment that must be
developed. In the transition from the older philosophies, SHINPADS allows a mix
of old and new equipment at a relatively small development cost for interfaces
between old equipments and SHINPADS. SHINPADS may not always be locally
optimal in the sense of indulging individual equipment and architectural
preferences, but neither are specifications or standards. The SHINPADS concept
is necessary if we wish to keep a capable navy at sea in the future.

HOW SHINPADS WORKS

The SHINPADS data "bus" consists of two triaxial cables connecting all
systems on the ship, carrying serial digital data at a ten megabit per second
rate. One of these cables carries out a polling function to determine the users
who wish to send messages on the bus. The second cable carries data. Polling
goes on while data is being transmitted, and thus the full capacity of the cable
is available for data.

Intelligent User Connection

Intelligent users connect to the bus via a Bus Access Module (BAM) and a
node. The BAM consists of a passive tap to the bus cable, one card and a self
contained power supply. The taps, because they contain only a few passive
components, are very reliable. Each BAM contains amplifiers which can put
signals onto the bus cable, and which regenerate the received bus signal and
pass it on to up to 4 nodes.

The basic node is a set of six cards. For transmission, it passes messages
from the user to the BAM and onto the bus. For reception, it screens messages
from the bus for those the user has declared an interest in, and passes these on.
This message screening is an essential function to prevent the user from the
overhead of examining all bus message traffic. The node handles all the bus
management functions for the user so that the user need not know any protocols
at this level. The node hardware interface is either NATO serial interface
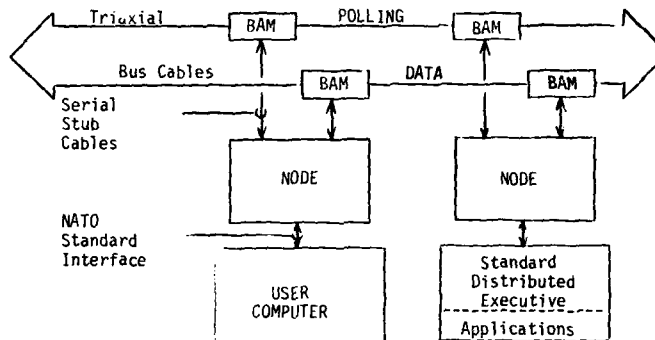STANAG 4153 or a NATO parallel interface STANAG 4146.

Figure 2 Basic SHINPADS Bus

The user, a computer of some sort, sees a standard NATO interface, and if
he is a UYK 20, 502 or 505 he sees at an application program level a standard
computer executive which provides him among other functions   a handler for
sending and receiving messages on the bus. He is able to send messages at four
levels of priority to either specific receivers or to groups of receivers in a
true broadcast mode. He may address his messages by either physical addresses
(ie, node number 7) or by .message content addresses (ie, Navigation Data). He can
receive messages either addressed specifically to him or broadcast   , but
he receives only the messages he has declared   he wishes to see. His
own address can also be logical or physical. There is nothing in the hardware
that predetermines who he is or what he is doing.

Dumb Data Transmission

Fast dumb data is typically display information which comes from a sensor
directly to a display. This data may be in many different formats: radar PPI
or A-Scan, TV formats, or random points. In order to achieve the aims of
SHINPADS, it is necessary to have an intelligent display which can handle any
sensor. We have developed such a display at Computing Devices in Ottawa.

The SHINPADS Standard Display (SSD) can handle any type of radar; framing
sensors such as FLIR or TV; line scan sensors such as Sonar or Infra Red; or
direct writing using any of several user-selectable patterns into its four
million bit video memory. The display is normally interfaced to a microcomputer
which handles local operator and tactical functions, and which communicates
with other systems through the data bus. The display includes a graphics
package and full NTDS symbology. Sensors are connected to the display through
one or more switchboards which allows any display to view any sensor and thus
provides the required flexibility and redundancy.

Low data rate dumb data is most reasonably handled by providing area
concentrators throughout the ship to accept dumb information in the form in
which it is produced, and convert it to bus format. The concentrator would be
a small standard micro computer. Examples of dumb data are wind speed, wind
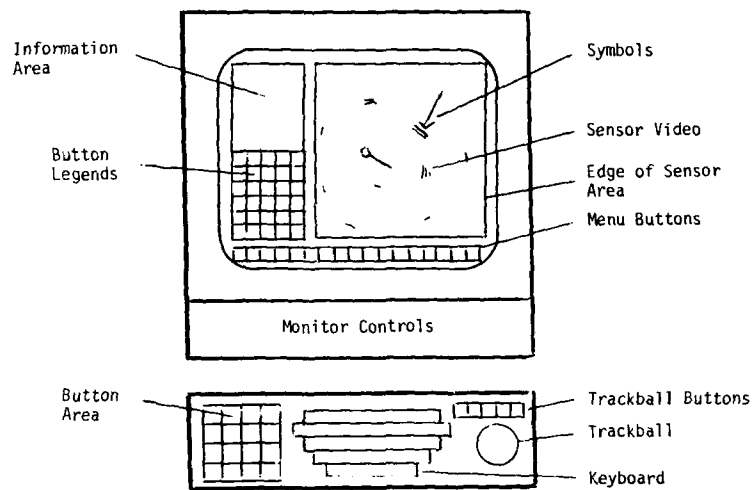direction, ship speed, compartment flooding indicators, etc.
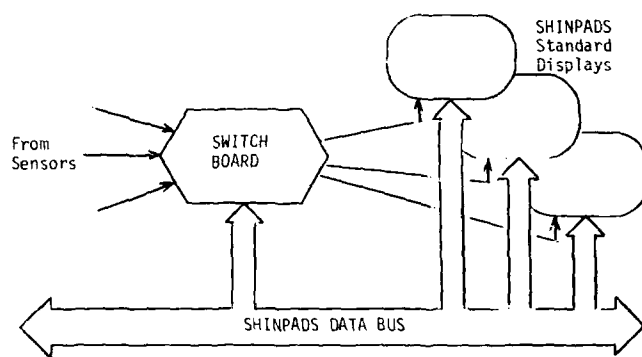
D2 2-4

Figure 3   SHINPADS Standard Display

Figure 4   Display Connection

TYPICAL SCENARIO

Consider a typical scenario when an operator at sea detects a potential target. The commanding officer and the operations officer would command their displays to select the sensor which had detected the target. The display would pass this command the bus to the switchboard(s), and the switchboard would connect the appropriate video to the displays. The captain would tell the operator to change the mode of the sensor. The operator, through his display and the bus, would send the appropriate orders to the sensor to change the mode. A separate processor on the bus, the Threat Evaluation and Warning processor, would assess the danger this target (which is stored in the Track File Management processor) posed the ship, and would notify the command. The captain would order a weapon assigned to the target. The operations officer instructs the Fire Control computer to compute a solution on the indicated target. The Fire Control computer would pass the results of its calculation on to the Weapon Control processor at the weapon. Steering and engine orders would be passed on the bus to the micro-processors controlling the rudder and machinery. The captain, from his display, would give the order to fire which would be passed via the bus to the Weapon Control processor and fire the weapon.

Nothing in this scenario presupposes which sensor or which weapon will be used. All data is available, and there is nothing in the hardware to prevent (for example) the ASROC from being assigned to a sea plane. If checks and restrictions are to be imposed, these restrictions will be included in the system software according to the current tactical doctrine and not pathologically bound into the wiring of the system.

REDUNDANCY AND FAULT TOLERANCE

Each node can connect to up to 6 bus cables, only two of which are required for full data communication. There is no pre-assignment of function, and any cable can be used for either polling or data transmission. Furthermore, the cables can be geographically distributed in the ship to ensure that there is no concentration where a single combat casualty could knock out all of them. Thus, at least five cables of the six must fail before the system will be down. Cable reconfiguration is done without effect on the user.
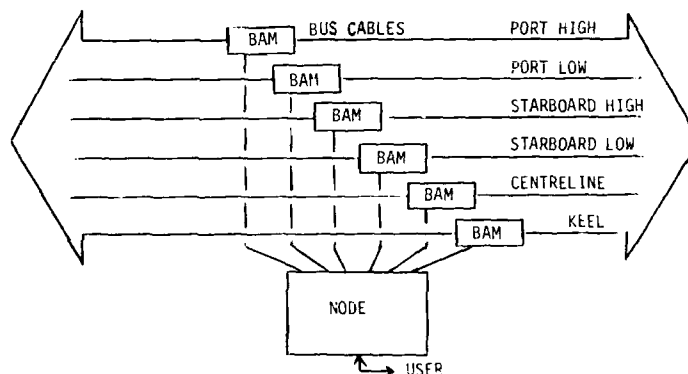

Figure 5 Cable Redundancy

D2 2-6

Any node can be a bus controller by the addition of one card. Thus there are as many alternate bus controllers as required by the system designer. If the primary bus controller ceases to operate for any reason, an alternate will automatically pick up the task and re-establish the polling sequence; if this also fails, another will pick up; and so on to the limit of bus controller nodes. Controller changes are also invisible to the users.
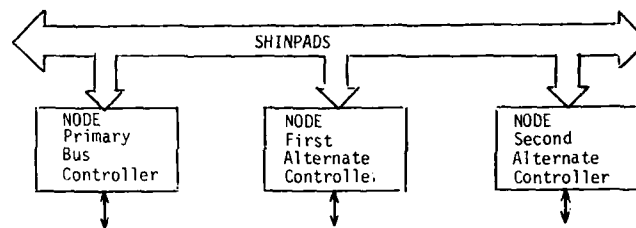

Figure 6   Bus Controller Redundancy

Nothing in the processors distinguishes them functionally from each other except the software they are running. Thus, should a processor fail - for example, our fire control processor in the typical scenario - then another processor can load in the fire control software over the bus and pick up the function. There are as many backups for a processor in the system as there are processors in the system; the least important task, whether defined in a pre-arranged sequence or by operator input, can always be shed to take on a more important task.

Because any display can present any sensor through the duplicated switchboards, failure of a display is not the catastrophy it once was. Every display is a spare for every other; capability is degraded but in a graceful fashion.

Only the leaves of the system, that is the sensors and weapons themselves, cannot be bypassed in case of a fault. Only duplication of the sensors and weapons can provide redundancy at this level. All other components in the integration system can suffer multiple faults and still continue to function.

SHINPADS STATUS IN FALL 1981

Standardization

We have established within the Navy a policy on standardization which requires the use of certain specified digital units in all development and production projects. Presently listed components include the AN/UYK-505 mini computer, the AN/UYK-502 micro computer, the AN/USH-26 cassette tape drive and the AN/UYQ-69 alphanumeric display. The AN/UYK-505 is the extended memory version of the Sperry AN/UYK-20 and is in production. The AN/UYK-502 micro computer was developed by DND and Sperry Univac as a software compatible "low end" version of the AN/UYK-20 instruction set architecture for use in distributing intelligence throughout the ship, and is now in production in Winnipeg. The display and tape drive are USN standards. The USN standard software executive, SDEX, is also our standard as is the CMS-2M compiler and the MTASS program support software which we have in a multi user program generation center in Halifax.

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Reaching standardization status are the SHINPADS Standard Display, now at EDM contract at Computing Devices in Ottawa, and the data bus Node, also at EDM contract at Sperry Univac in Minneapolis. The data bus nodes will also be produced in Winnipeg. The Bus Access Module is being brought to production status by Sperry Univac in Minneapolis using internal research and development funds.

Standard digital equipment is being specified in current contracts for electronic warfare, machinery control, message handling, active and passive sonar developments, variable depth sonar towing monitor systems, submarine fire control systems, and many smaller development projects.

Bus Structure

The SHINPADS data bus was first demonstrated in ADM form in the fall of 1979 using 6 nodes, 32 BAMs, and 3 cables at Sperry Univac in Minneapolis. It has travelled widely to subsequent demonstrations in Weisbaden Germany, and to Japan, and is currently in a 3 node/3 cable form in the Sperry plant here in Ottawa. The EDM system is now being set to work in Sperry Univac in Minneapolis.

SUMMARY

SHINPADS is an architecture and integration concept which can provide functions for future ship systems which are simple, capable, flexible, supportable, and survivable at reasonable cost. Necessary components for the system are either in production or are at contract for the last stage before production. There is strong international interest but so far other nations are still in a catchup situation. SHINPADS is ready to be designed into systems now.

FOR FURTHER READING

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2.   Kuhns, R.C., "SHINPADS Serial Data Bus," presented ASNE Day 1979, Naval Engineers Journal, Vol. 91, No. 2 (April 1979).

3.   Carruthers, J.F., Cdr., CF & P.F. Williams, "SHINPADS - Shipboard Integrated Processing and Display System", Proceedings of the International Naval Technology EXPO 78, Rotterdam, Netherlands, 6-8 June 1978.

4.   Thomas, D.M., "SHINPADS Standard Display, presented ASNE Day 1979, Naval Engineers Journal, Vol. 91, No. 2 (April 1979).

5.   Carruthers, J.F., Cdr.,; CF, "SHINPADS - A Ship Integration Concept", Proceedings of the FIFTH Ship Control System Symposium, Annapolis, Md., 30 Oct. -3 Nov. 1978.

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SHIPBOARD DATA MULTIPLEX SYSTEM
ENGINEERING DEVELOPMENT ASPECTS AND APPLICATIONS

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ABSTRACT

The Shipboard Data Multiplex System (SDMS) is a general-purpose information transfer system directed toward fulfilling the internal data intercommunication requirements of a variety of naval combatant ships and submarines in the 1980-1990 time frame. The need for a modern data transfer system of the size and capability of SDMS has increased in unison with the sophistication of shipboard electronic equipment and the associated magnitude of equipment-to-equipment signal traffic.

Instead of miles of unique cabling that must be specifically designed for each ship, SDMS will meet information transfer needs with general-purpose multiplex cable that will be installed according to a standard plan that does not vary with changes to the ship's electronics suite. Perhaps the greatest impact of SDMS will be the decoupling of ship subsystems from each other and from the ship. Standard multiplex interfaces will avoid the cost and delay of modifying subsystems to make them compatible. The ability to wire a new ship according to a standard multiplex cable plan, long before the ship subsystems are fully defined, will free both the ship and the subsystems to develop at their own pace, will allow compression of the development schedules, and will provide ships with more advanced subsystems.

This paper describes the SDMS system as it is currently being developed in the Engineering Development stage by the U. S. Navy. The results of preliminary design studies on the DDG 47 Class and SSN submarine platforms are also presented.

INTRODUCTION

The ultimate use of SDMS on any particular Navy ship or submarine platform depends upon: (1) successful demonstration of the operational effectiveness and suitability of SDMS through shipboard Technical and Operational Evaluation (TECHEVAL/OPEVAL); (2) establishment of a baseline SDMS configuration for each hull class and then preparation of detailed implementation plans; (3) performance of land-based integration tests unique to the particular platform. Upon completion of these, a determination will be made to introduce SDMS into specific classes. The TECHEVAL/OPEVAL considerations are being addressed as part of the basic SDMS engineering developmental program. The following dissertation concentrates on the platform application studies.

In 1979 the Navy completed preliminary SDMS design applications studies on two platforms: DDG 47 Class ships and future Attack Submarine (SSNs). These studies were conducted in parallel with the design of the SDMS Engineering Development Models (SDMS-EDM). Factors unique to each platform studied dictated different approaches for incorporating SDMS.

The study of DDG 47 Class ships resulted in a definition of the hardwired circuits that could be replaced with SDMS. This study not only examined the replacement of conventional wiring but also the elimination of certain switchboards and

signal data converters. As a practical matter, the DDG 47 application study was conducted on a "bottom-up" basis (fitting SDMS into the existing designs).

The other SDMS application study developed a preliminary design applicable to future Attack Submarines (SSNs) and FY8 SSN in particular. Here a "top-down" approach was used. In this approach SDMS was used as a system integration medium to achieve the integration of advanced displays, interior communications, navigation, and selected combat system elements into an efficient and effective system. Since space and weight savings were of primary importance, the system design demanded: (1) that the packaging of SDMS be tailored to space allocated, and (2) that selected data conversion functions be provided by special purpose SDMS Input/Output Modules (IOMs).

These and other fortLcoming application studies, together with the basic SDMS Development Program, will provide the basis for an SDMS implementation program which the U. S. Navy can support with high confidence.

SHIPBOARD DATA MULTIPLEX SYSTF .SDMS) DESCRIPTION

The Shipboard Data Multiplex System (SDMS) is a modular, general-purpose multiplex system capable of transferring the majority of internal data intercommunication signals wherever needed aboard ship. Instead of miles of unique cabling that must be specifically designed for each ship, SDMS will meet present and future information transfer needs with general-purpose multiplex cables that will be installed according to a standard plan that does not vary with changes to the ship's electronics configuration. SDMS, as a data transfer system, will serve to interconnect a wide variety of shipboard systems and equipment such as: weapon direction systems, command and control systems, combat information centers, damage control centers, navigation equipment, displays, propulsion and electrical machinery control devices, and electrical power distribution control.

System Architecture

The design of SDMS is modular to meet the level of redundancy and total information transfer bandwidth requirements of a wide variety of platforms whether it be a frigate, an aircraft carrier, a submarine or a shore test facility. The modular building blocks are multiplex buses, Traffic Controllers (TCs), Area Multiplexers (AMs), Remote Multiplexers (RMs), Area Remote Multiplexers (ARMs), and Input/Output Units (IOUs). Figures 1 through 4 are functional block diagrams showing various SDMS architectures.

The dual stage, five primary bus configuration shown in Figure 1 is intended to be modularly expandable to handle the largest ship platforms. Figure 2 shows the single stage, three primary bus configuration which will provide a great deal of versatility in the smaller ship platforms. Figure 3 shows the basic dual stage system with single stage (e.g., ARMs) judiciously used where low-density transfers are required. Another aspect of SDMS's flexibility is shown in Figure 4, in which primary buses 1 and 2 are essentially dedicated to the subsystems communicating through the ARMs although they also have the ability to communicate with all other user systems via their connections to primary buses 3 and 4.

SDMS provides for interchange of information between AMs by both time division and frequency division multiplexing over a fivefold redundant data bus, under the control of Traffic Controllers. Each of the 5 primary cables has 5 carrier frequencies for a total of 25 channels. Twenty of these channels are used for message transfer between AMs. The remaining five channels are assigned one each to the five Traffic Controllers. One Traffic Controller is connected to each primary cable. In large systems, up to 16 dual-redundant Area Multiplexers (AMs) and up to 2 Maintenance Units (MUs) shall be connected to each of the primary buses, and up
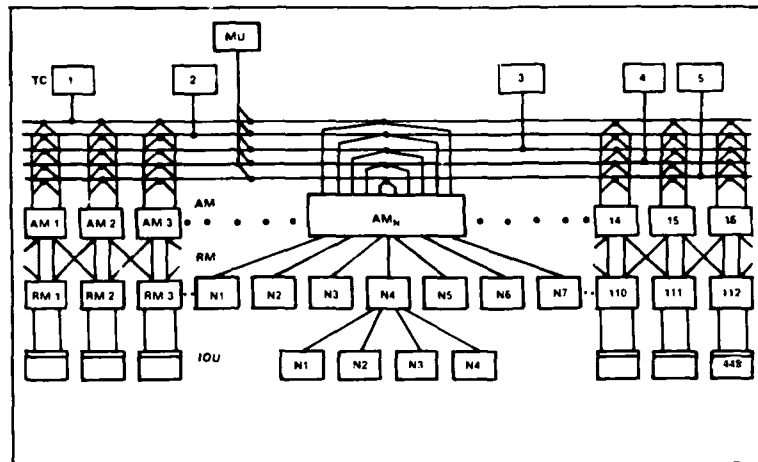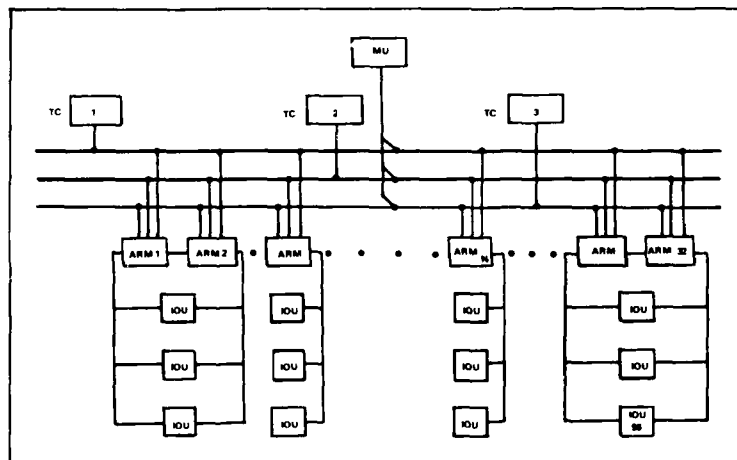
Figure 1. SDMS Architecture: Dual Stage.

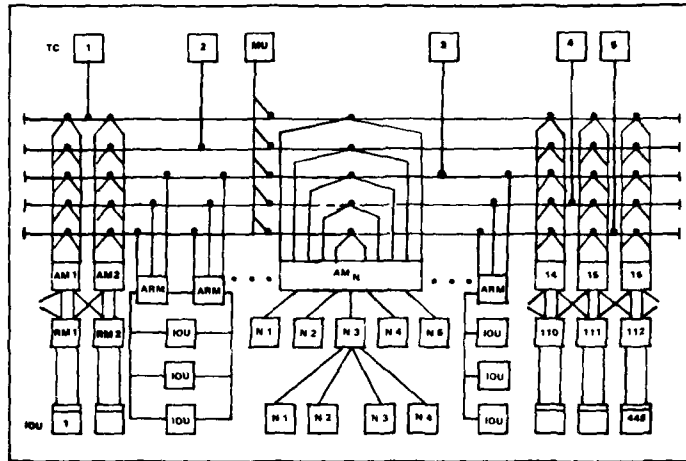Figure 2. SDMS Architecture: Single Stage.

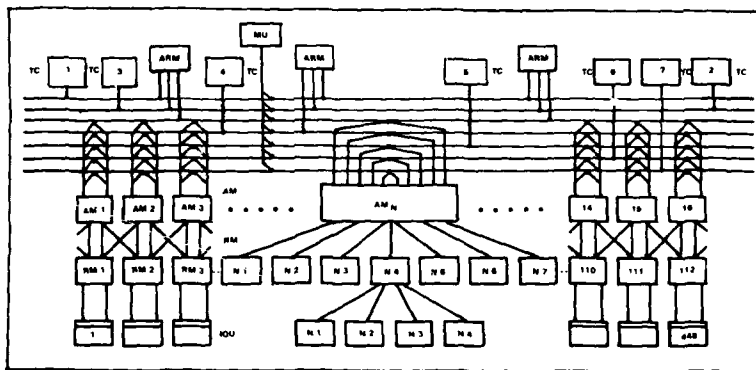Figure 3. SDMS Architecture: Hybrid Configuration.

Figure 4. SDMS Architecture: Hybrid/Dedicated.

to 112 dual redundant Remote Multiplexers (RMs) shall be served by the AMs. Each RM shall directly serve up to four Input/Output Units (IOUs). Two different sizes of IOU shall be provided having capacities of 8 and 16 Input/Output Modules (IOMs), respectively. In smaller systems, up to 32 ARMs (16 dual-ARM pairs) and 1 MU shall be connected to each of the primary buses. Each ARM shall internally accommodate up to four IOMs and shall directly serve up to three external IOUs.

The Input/Output Units serve as the normal user access point to SDMS, and are located as close as possible to user subsystems.

One or more Remote Multiplexers will normally be located in each ship compartment that contains any significant quantity of signal generating or receiving equipment. The Area Multiplexers will be located in interior compartments that are central to high densities of Remote Multiplexers, and the Traffic Controllers will be distributed among several interior ship compartments. The Area Remote Multiplexer (ARM) basically performs the functions of both the AM and RM. It can be used in locations where signal densities do not merit using an AM and RM combination. A Maintenance Unit (MU) will be located in a compartment that is convenient to Interior Communications (IC) maintenance personnel.

System Operation

Figure 5 is a simplified system block diagram that delineates the signal path between two user subsystems. Suppose User Subsystem B has requested an update of the interface signals from User Subsystem 4. The signals are first coupled into a local Input/Output Unit, then to the Remote Multiplexer, shown on the left, that typically would be located somewhere near User Subsystem A. The Remote Multiplexer would assemble samples of each of the signals from User Subsystem A along with any other user equipments that transmit data to the same Remote Multiplexer at the other end of the path, and forward this message to the nearest Area Multiplexer shown on the left. The Area Multiplexer will translate the baseband time-division-multiplexed message into a frequency division-multiplexed signal on one of the four data channels in the 40-80MHz band.[1] Access to one of the five primary multiplexed buses that run throughout the ship is controlled by a separate Traffic
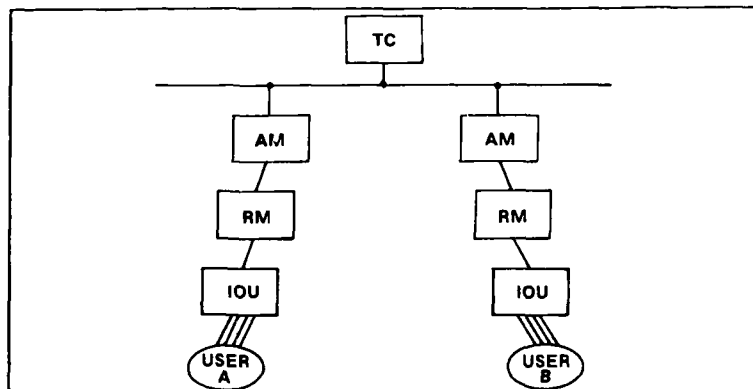

Figure 5. SDMS Signal Flow

D2 3-5

Controller for each bus. At the destination the message from User Subsystem A follows the reverse path to reach User Subsystem B. It is picked off the primary bus by the nearest available Area Multiplexer, where it is converted back to a baseband time-division-multiplexed message for subsequent distribution to the users via the Remote Multiplexer and Input/Output Unit nearest User Subsystem B. Note that this entire process occurs essentially in real time; that is, SDMS is not a store-and-forward information transfer system. As each subsystem signal is converted from its original analog, synchro, digital, or discrete form, it is simultaneously transmitted in time-division-multiplex form through the Remote Multiplexer and in the frequency-division-multiplex form through the Area Multiplexer. At no point in the system is the entire message stored so as to incur a data staleness problem.

System Control Mechanization

SDMS provides an unusual approach toward its control mechanization in that it is totally asynchronous and distributed. Asynchronous means "free running," or not governed by a central clock. The asynchronous distributed control approach was chosen after a thorough analysis of both the technical and operational requirements for shipboard information transfer. It essentially provides the ability: (1) to establish a data exchange path between user subsystems with full local control of information transfer parameters such as message length, message update rate, message priority, etc., and (2) to make changes in message transfer parameters and in system interconnectivity as the requirement occurs, with low cost, with simple field verification, and without the possibility of degrading or disabling the entire ship if errors are made. This approach also allows SDMS to efficiently handle both periodic signals and aperiodic events like alarms which randomly occur once an hour, once a day, or once per mission.

Distributed control means that the basic control mechanism determining what data will be sent at what time, from what signal source to what signal destination (sink), is not located in a central device but is distributed through the system. No software is used in the control of SDMS. Instead, the transfer of data between two subsystems is controlled by two "plug-in" message Programmable Read-Only Memories (PROMs)--one in the SDMS terminal serving the source, and one in the sink terminal. The coding in these two PROMs controls all aspects of the subsystem message transfer/update rate, priority, addressing, etc., completely independent from all other messages within the system. To establish a new data path via SDMS, one simply has to insert appropriate interface cards (input and output) and program the PROMs in the Remote Multiplexers located nearest the transmitting and receiving equipments.

User Interface to SDMS

The IOU provides the user with access to SDMS via signal conditioning circuits called Input/Output Modules (IOMs). IOUs can be modularly implemented with up to 4 boxes capable of handling a maximum total of 64 input/output modules per Remote Multiplexer.

Input or output modules of the synchro, digital data, analog, or discrete variety can be separately plugged into the Input/Output Unit to meet the signal distribution requirements of the user subsystems located in each compartment. The slots into which the Input/Output Module cards are inserted are not dedicated. That is, any mixture of synchro, digital, analog, or discrete cards can be inserted at random into these slots.

The Engineering Development Model of SDMS provides a selection of Input/Output Modules (IOMs). These IOMs have been developed for the purpose of converting signal types noted in existing shipboard electronic equipments into a standard

digital format that is required for transmission within SDMS. However, the use of these modules is flexible in that user subsystem signals can enter SDMS in one format and exit in another, if desired. Additional modules will be developed as the need becomes apparent.

FY80 SSN STUDY

Approach

The FY80 SSN preliminary design study was initiated with an agreed upon set of ground rules that collectively can be categorized as a top-down approach. These ground rules were developed during a previous conceptual design study which addressed where SDMS might save space, improve user system capability, provide future growth, but not necessarily provide an initial cost savings. To this extent the signals to be multiplexed and guidelines for locating, packaging, and maintaining SDMS hardware were provided at the beginning of the study. Since several parallel studies on other interfacing subsystems were also being performed, the full integration on other interfaces was encouraged. The Ship Data Display Unit (SDDU) and the Ship Control Panel were two subsystems of particular interest. In addition, the elimination of subsystem interfaces which required the use of 400Hz power was considered.

Results

During the course of the study the original signal list was slightly modified, with SDMS's major user interfaces being with the Navigation, Ship Control, and Computer Subsystems. Examples of the types of functions transferred are ship's speed and depth sensor data and their display; ship's heading, pitch, and roll; position of submarine control surfaces; and cavitation hydrophone data. The SDMS equipment complement consisted of:

2 Traffic Controllers and Primary Buses
6 Area/Remote Multiplexers (ARMs)
7 Input/Output Units (4- and 8-slot types)
32 Input/Output Modules
1 Maintenance Unit

In order to meet the requirements for minimum use of volume and deck space, the Traffic Controllers, the Maintenance Unit, and two ARMs were packaged into a single water-cooled enclosure.[2] In addition, two other ARMs were to be located in the Ship Control Panel (SCP). A net weight saving of 1.5 tons and 85 cubic feet of volume was achieved using SDMS. While design approaches for the ARM had been developed during the advanced development stages of the SDMS program, its final specifications and ultimate hardware development were initiated as a result of the submarine effort. In advanced development the ARM was considered as a cost-effective alternative to a combination AM and RM in small ship applications or in limited applications on larger ships. The study identified six IOMs unique to the FY80 SSN. They are the EM Log, BRD-7 Time, Demand Digital, Depth, Cavitation, and Periscope RPM. Figure 6 illustrates the fully integrated EM Log interface.

All ship systems which are attached to the SDMS data bus have full access to the information on the data bus. For the operator, this capability was provided through a Ship Data Display Unit (SDDU) plasma display, with touch-panel selection of the information displayed. The SDDU information is displayed in characters and graphics which can provide more information than present displays, and yet the SDDU requires significantly less space than the displays it replaces. Programming the SDDU microprocessor to perform arithmetic computations can be accomplished so that graphic presentation and recommended actions can be given to the operator to aid in his decision making.
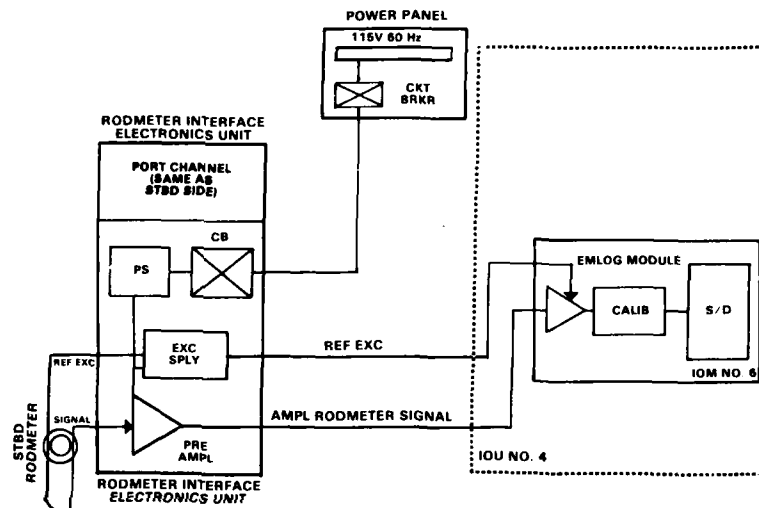
D2 3-7

Figure 6. EM Log Rodmeter Interface.

In conjunction with the SDMS installation, the previously required central interior communications switchboard power distribution and action cutout (ACO) switching provisions were deleted. The ACO functions were incorporated into the IOUs. Requirements for switching also could be met by modifying user equipments or by providing a small switching panel designed to meet established needs. A combination of both approaches will most likely be used. This will provide maximum flexibility in a minimum amount of space.

In that SDMS is designed for easy expansion up to a third primary bus and 32 ARMs, growth capacity is more than adequate. The total FY80 SSN data load was estimated to be approximately 100K bits per second and is relatively small considering the recommended configuration's gross capacity of 9.6M bits per second. Reconfiguration or relocation of the present systems serviced by SDMS will not require major redesign of ship's cabling, interfaces, and wireways. The interconnections will be accomplished with short cable lengths from users to Input/ Output Units (IOUs), which provide access to and from the data bus. To install a new user system would require only short lengths of cable linking it to the IOU in the vicinity of the new equipment. Once connected to the IOU, the new system has full access to the ship's data bus. This feature significantly simplifies installation of new equipment and improvement of installed equipment without major changes to cable runs and wireways.

The SDMS Maintenance Processing Unit (MPU) continuously monitors the entire SDMS. When a fault occurs, both an audible and a visual alarm are generated and the MPU indicates which part has failed, down to the lowest replacement unit (LRU). The MPU may be read and the LRU replaced by third class IC personnel. Microminiature circuit repair facilities available at the Navy's Intermediate Maintenance Activities should be able to repair the LRUs and return them to the supply system.

D2 3-8

Although the elimination of those interfaces (e.g., BRD-7, WLR-2) which required the use of 400Hz power was encouraged, none were eliminated, the reason being that the redesign of those equipments to incorporate a digital interface could not be assured. As a result, the existing 400Hz synchro interfaces were documented in the study report.

DDG 47 STUDY

Approach

In the first quarter of 1978 the study to develop an SDMS-based interface design for the DDG 47 Class ships was initiated. At the onset it was recognized that the DDG 47 conventional design was nearly complete and that an SDMS application would necessarily incur redesign costs which would otherwise by avoided in a new design. Nevertheless, since the SDMS development schedule is compatible with many of the class follow-on platforms and since some design changes are anticipated, it appeared that the DDG 47 Class might be a suitable place to introduce SDMS into the fleet, even if in a restricted application. Therefore, the design approach was to initate the analysis at a broad-scale applications feasibility level and then to develop a design which concentrated on the high payoff areas.

The study was organized into phases. Phase I was a data gathering process which required the tabulation of the DDG 47 systems interface data. Phase II brought in cost analysis and defined various configuration options and associated costs. Phase II produced the conceptual design for the SDMS configuration that will be most beneficial to the DDG 47 Class, as constrained by the ground rule of minimal redesign impact on the AEGIS Combat System.

Results

Phase I analysis resulted in the tabulation of over 6,000 point-to-point data paths that can be multiplexed in an SDMS configuration. More than two thirds of those are for simple two-state discrete signals and less than a third are for synchro and analog scalar type signals. Data was accumulated for another 300 NTDS digital interfaces primarily for NATO interface analysis. Since most of these signals do not cross compartment boudaries and since multiplexing these signals is likely to incur some software modifications, the multiplexing feasibility of these signals was addressed only in a generic sense. No final conclusions with respect to multiplexing were drawn other than the observation that most of the signals require a data throughput capability which is less than that provided by each of the 20 SDMS data channels. About 5,000 of the 6,000 point-to-point data paths r signals traverse compartment boundaries and therefore constitute the primary multiplexing candidate set. About 185K feet of cabling is required for those 5,000 signals in a conventional wiring design.[3]

In addition to the analysis of signals, studies were conducted to assess the functions performed by various switchboards and data conversion devices to determine whether SDMS could provide those same functions, thereby enabling the elimination of those devices in an SDMS-based design. It was determined that more than a dozen of such devices could be replaced, but significant systems redesign efforts would be required in many cases. An important observation made from these analyses is that in a top-down design, which includes the integration of SDMS from the outset, switching and conversion functions can be performed by SDMS at costs equal to or less than those for conventional counterparts.

The final leg of Phase I analysis developed a nonoptimized and transparently applied SDMS configuration (e.g., to reflect only the multiplexing of the point-to-point data paths) to obtain a preliminary assessment of the numbers of

SDMS elements required and to assess SDMS performance. The SDMS configuration consisted of the following elements:

      5 Traffic Controllers and Primary Buses
      8 Area Multiplexers
     27 Remote Multiplexers
     99 Input/Output Modules
  1,210 Input/Output Modules
      1 Maintenance Unit

Using a computer program which simulates SDMS performance for a given configuration and data load, it was determined that the average message transport delay was 182 microseconds. The data load, which consisted of the 5,000 inter-compartment signals plus a few NTDS digital interfaces, had a 1.9M bit-per-second throughput rate.

Finally, although the Phase I analysis was geared toward developing a data base and performing a preliminary sizing/performance analysis, it became apparent that even the nonoptimized SDMS configuration applied on a transparent basis can result in cable length and weight savings. Approximately 185K feet of conventional cabling would be impacted with a net weight reduction of about 9 tons. The replaceable switchboards and conversion devices represent another 5-ton weight reduction potential.

Armed with the data base and SDMS performance analysis results from Phase I, the project directed the Phase II efforts toward the refinement of various SDMS applications configurations options to study the potential impact of installation in the DDG 47 Class. In Phase II, the applications options tradeoffs were examined and economics impact was considered.

The first and probably most important lesson learned is that, excluding the consideration of design development costs, SDMS will break even at best on costs with respect to cabling replaced in the DDG 47 Class. Therefore, the use of SDMS in the DDG 47 Class should be predicated on factors other than potential dollars saved due to reduced cabling. This conclusion is likely to hold for most top-down design approaches (where no redesign costs are incurred) as well as in almost all retrofit design approaches.

The second and perhaps as important conclusion is that while it was known that ship's systems invariably include switchboards and data converters that in most cases can be replaced by SDMS, it was not generally known that multiplexing networks (that are potentially replaceable by SDMS) are already in Navy ships. In fact, it was determined that the DDG 47 design includes two such multiplexing networks (e.g., ORTS and PAMISE) although neither is a broad based network such as SDMS. Furthermore, it was determined that new subsystems designs are likely, in many cases, to require some type of data distribution/multiplexing network. Therefore, the question, as had been presupposed at the outset of the project, is not whether multiplexing should be introduced into the fleet, but rather how should it be implemented. More specifically, the tradeoff is one of the use of a widely applied and standardized network such as SDMS vice the use of smaller limited application, but tailored, specialized multiplexing networks.

Going back to SDMS application to the DDG 47, while it is clear that SDMS does not result in a net cost saving when applied only to replace cable, the cost picture becomes substantially better if switchboards and conversion devices are replaced. In fact, a top-down design which uses SDMS in place of such devices is likely to be significantly, but not overwhelmingly, cheaper than the conventional counterpart. But in the case of the DDG 47 Class, the potential savings are not enough to overcome the initial DDG 47 systems redesign costs. Furthermore, exten-

sive design changes to the AEGIS Combat System are considered undesirable at this time due to the technical and schedule risks involved.

Therefore, the issue facing the study project was whether to recommend the maximum application of SDMS to the DDG 47 Class and attempt to justify the increased expenditures on the basis of weight savings, enhanced survivability, and increased flexibility, or to search for some lesser application which minimized expenditures and zeroed in on the high payoff areas. The project decided to recommend that SDMS be installed in the DDG 47 Class on a limited application basis for the following reasons.[4]

First, to establish what constituted a high payoff area it was necessary to address the advantages provided by SDMS and then determine how these advantages impacted various applications areas. In the Navigation area, it was observed that the weight reduction payoff was substantial because the heavier types of cabling and the major portions of the Main Interior Communications Switchboards were eliminated. Also in this area, the enhanced survivability provided by SDMS is important because these Navigation signals are critical to many user systems. Additionally, via the use of SDMS the switching of the Navigation Gyros can be automated and reaction time to a failed Gyro can be reduced. Therefore, the Navigation signals (about 200 signals) constitute a high payoff area with the important parameters being weight reduction, increased survivability and switching flexibility. However, since only about 6,000 feet of conventional cabling is replaced by multiplexing in this area, cabling cost savings do not offset the costs of the multiplexing hardware required. Nevertheless, the functional gains are readily identifiable and it is clear that a specific systems enhancement results from the expenditure.

A second area of fruitful application is the Damage Control network.[4] Unlike the more critical Gyro signals in the Navigation area, each Damage Control signal is of lesser relative importance, and therefore, enhanced survivability is not as important. However, the use of the SDMS in this area impacts about 500 signals and 60K feet of cabling. Since most of these signal types are discretes, which are the cheapest signals to multiplex with respect to I/O conversion costs, and since one third of the 185K feet of cabling is impacted, the Damage Control network provides a good weight reduction return for dollars spent. More importantly, the Damage Control data now becomes available at many points other than Damage Control Central and can enable the implementation of a backup Damage Control station/display without the need for substantial amounts of new cabling. Additionally, if a computerized Damage Control Central evolves (the present one is strictly a non-intelligent analog display), SDMS can readily deliver the data to such a complex in a digital format. Conversely, if SDMS is not implemented in this network and a computerized complex is to be implemented, a new data converter requirement will arise. Damage Control is a good example of the type of network which will, when computerized, require either new data converters and/or a new data distribution network. It illustrates a specific example of how SDMS can provide an important payoff other than, but in addition to, the replacement of cabling.

Another applications area which results in an immediate payoff is the pooling of teletype consoles. In this application, which involves only a small amount of cabling, the SDMS switching capabilities are used to enable the C&D computers to access and share the low data rate teletypes. By so doing, four teletype consoles can be eliminated and a 2-ton weight reduction results. Furthermore, the computers would now have access to any other data in SDMS and can communicate with any devices (e.g., present or future) connected to SDMS.

In each of the above applications areas the use of SDMS in place of the conventional network results in a specific advantage or set of advantages. Cost analysis has shown that the implementation of any SDMS configuration in the DDG 47 will

not pay for itself. This is due largely to the redesign costs associated with this bottom-up design approach. By limiting the configuration, SDMS becomes introduced into the DDG 47 Class at minimal costs and provides immediate returns as described above. Furthermore, SDMS would then be resident to accommodate the data distribution/conversion/switching capabilities that will be necessary to support new systems as they are integrated into the design. The consequence of not implementing SDMS is that more specialized converter boxes, switchboards, and specially tailored data distribution/multiplexing networks will evolve, and from the preliminary cost analysis conducted on such devices and networks already in the DDG 47, it appears that these new elements will be more expensive than SDMS in the long run, primarily because unnecessary new design costs will be perpetuated.

As an aftermath, it is clear that the best way to integrate a wide scale application multiplexing network is to include it in the initial systems design. In the case of the DDG 47 retrofit design, maximum appliction is not cost-effective, but the limited scale application selected results in near-term gains and anticipated long-term advantages which are judged to be worth the expenditures.

CONCLUSIONS

The DDG 47 and SSN submarine studies both developed SDMS configuration designs which do not make maximum use of SDMS, but rather restrict SDMS appliction to those areas which result in an immediate payoff. While the two applications are similar in that regard it is interesting to note that they each resulted from two different design approaches. A bottom-up design approach drove the DDG 47 application while a top-down approach was used for the SSN submarine application.

At the outset of both of the studies it was preconceived that saving cable was the primary applications factor, but it was subsequently learned, and is in fact reflected in the configuration designs, that benefits other than cable savings are probably more important from an overall ship design point of view. For example, in the DDG 47 design, enhanced survivability and automated switching is particularly important in the Navigation area. In the teletype console pooling application, equipment reduction and space/weight savings are important. In the Damage Control application, the availability of Damage Control data at alternate locations is important plus the fact that the data can be delivered in digital form to input to a computer. In the submarine study, SDMS was used primarily to save space via system integration and equipment reductions and to facilitate interface design where changes were already planned. In addition, SDMS in conjunction with the Ship Data Display Unit (SDDU) greatly enhanced the availability of Navigation data throughout the submarine. The major point here is that while SDMS saved cable in both applications, the major advantages of using SDMS related to factors other than cable savings. Furthermore, while multiplexing is what enables cable savings, it is the I/O adaptivity (provided by the IOMs) which makes possible most of these "other" gains. Cost analysis in the DDG 47 study revealed that more than half the cost of SDMS is attributable to input/output signal conditioning. This is probably why SDMS is not cost-effective when used only to replace cabling in the DDG 47 Class. In a "pure multiplexing" network the subscribers would all be required to "speak" the multiplexing language or, in other words, bear the burden of providing data in a standard format. Under such circumstances, it is likely that a "pure multiplexing" network would prove cost-effective as applied only to saving cable. But since this is not the case, it is apparent that SDMS application beyod the mere replacement of cabling is what is required if the cost of SDMS is going to be properly amortized. That is, in essence, the message implied by the designs developed for the DDG 47 and submarines.

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